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American Welding Society

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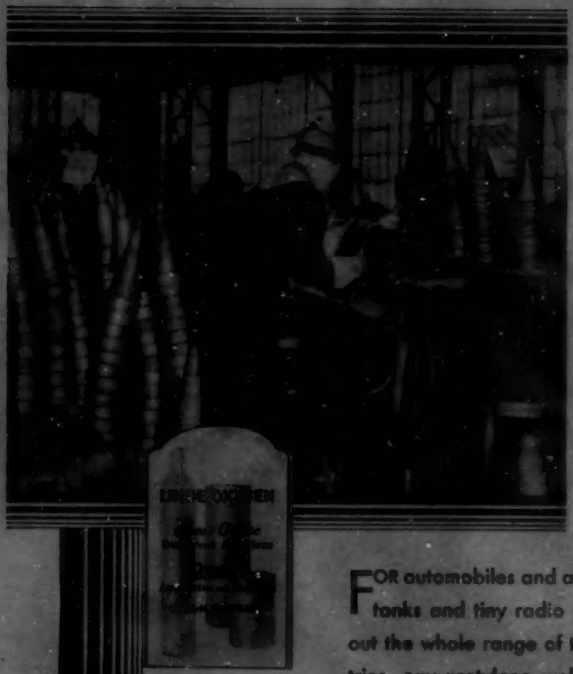

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JOURNAL

of the

AMERICAN WELDING SOCIETY

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AMERICAN WELDING SOCIETY
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Annual Meeting

By far the most successful Annual Meeting of the American Welding Society came to a close Friday afternoon, April 25. There was a registered attendance of about 225 at the technical sessions.

The meeting opened on Wednesday, April 23, with a business session and the report of the Tellers' Committee announcing the election of officers and directors. The President presented a condensed summary of the outstanding accomplishments and the activities of the Society during the past year. His complete report is published elsewhere in this issue.

Twelve technical papers were presented on a wide variety of subjects. Research work and mathematical analysis of stress distribution in welded joints were particularly stressed as was also the subject of structural steel welding.

An outstanding feature of the meeting was a discussion of the proposed specifications for fusion welding of drums or shells of power boilers. This meeting was presided over by F. R. Low, chairman of the American Society of Mechanical Engineers' Boiler Code Committee, and Editor Emeritus of *Power*.

Another special feature of the meeting was the showing of a slow motion French film of a study of the Metal Arc during proper and improper welding conditions.

A number of committees held luncheon and dinner meetings during the sessions.

The Structural Steel Welding Research Committee of the American Bureau of Welding provided an opportunity for the members of the Society to learn of the considerable progress made by the committee. Statistical reports were presented as to the number of specimens planned, prepared and tested. Stereopticon slides and discussions indicated in a general way the results obtained to date and the methods of analysis employed in correlating and examining the test data.

The Annual Meeting of the American Bureau of Welding immediately followed the Structural Steel Committee meeting at which were given a high spot review of the accomplishments of the several committees of the Bureau. The Annual Report of the American Bureau of Welding will be published in the Year Book of the Society. A special proposal was made by the Fundamental Research Committee which attracted considerable attention. This suggestion involved the arrangement of a tour of university professors to important industrial plants where they would witness a variety of applications of welding.

Special commendation is deserved by the Dinner Committee under the chairmanship of A. F. Keogh. Two hundred and sixty five members and guests enjoyed the Annual Stag Dinner and the entertainment which followed. The occasion was enlivened by the distribution of a number of door prizes to holders of lucky numbers. Souvenirs were received by all.

ANNUAL REPORT OF PRESIDENT

(Presented in abstract at the Annual Meeting of the Society, April 23, 1930)

Membership—The increase in membership which has marked each year since the organization of your Society in March, 1919, continues with accelerated pace. At the close of the Society year, March 31, 1930, the membership in all classes totalled 1343, a net increase for the year of 327 (32 per cent). Class A is the only one to show a net loss, it having been reduced by 3 (6 per cent). Class B shows a net increase of 121 and Class C of 116 (each 32 per cent). Class D, which a year ago showed a loss, now shows a gain of 71 (34 per cent). Class E remains unchanged with 3

honorary members. Class F shows an increase of 22 (105 per cent). The ratio of net losses to gains is 48 per cent, which shows further improvement over a year ago when it was 62 per cent, but this ratio is still higher than is desirable. The full results of an experiment in the Boston Section to concentrate on Class C membership were not realized until after the close of the Society year, and they are only partially reflected in the present report. Your national Committee on Membership is to be congratulated on the successful result of its efforts. A table of present class membership as compared with that of the preceding year follows:

Class	Membership March 31 1929	1930
(A) Sustaining Members	47	44
(B) Members	377	498
(C) Associate Members	360	476
(D) Operating Members	208	279
(E) Honorary Members	3	3
(F) Student Members	21	43
Total	1,016	1,343

Finances — For the year ending March 31, 1930, total receipts were $38,174.44 and total expenditures $36,223.64. The cash balance (which now stands $4,781.35) was increased by $1,950.80. Receipts were $3,157.11 more, and expenditures $2,449.95 more than during the preceding year. The Present Worth of the Society is $14,510.77, of which $5,269.50 remain invested in bonds, and $800.00 is reserved for the Miller Memorial Medal Fund. A detailed financial statement will be published in the JOURNAL.

Headquarters—The increased membership and activities of your Society have made necessary the securing of enlarged space and more assistance. Under the authority of your Board of Directors a suite of three rooms, with suitable storage space, has been secured on the sixteenth floor of the Engineering Societies Building, New York City, and the headquarters of the Society was moved into these offices in March, 1930. The clerical force has been increased by the addition of one employee.

Journal—During the past year the 12 issues of the JOURNAL totalled 1255 pages as against 1300 the previous year. It will be recalled that early in 1929 a reduction in number of pages of technical matter was made to offset a reduction in space taken by one large advertiser. It is satisfactory at this time to report that the revenue then lost has recently been substantially restored in the form of space taken by several new advertisers. Effort was made to compensate for the temporary reduction in size by publishing papers of even greater interest and value than in the past. The reaction to this effort, both within and outside of the welding industry, has been gratifying to the editor. A tabulation of JOURNAL space during the past two years follows:

Matter	Number of Pages Volume 7	Volume 8
Editorial	160	160
Technical	851	862
Advertising and Circular	289	233
Total	1,300	1,255

Meetings—The Annual Meeting was held in New York in April, 1929, with a registered attendance of 195 people. It included five technical sessions (which is the number scheduled for the present meeting), committee and board meetings, a lunch and a stag dinner.

The Fall Meeting occurred in Cleveland early in September, 1929, with a registered attendance of about 400 members and guests. Six technical sessions were held at which a total of sixteen papers were presented. Most of these papers dealt with the results of research work. One of the sessions was arranged in cooperation with a department of the American Society of Mechanical Engineers. Provision was made for inspection trips, aviation flights and social entertainment participated in by the ladies. In order to facilitate the inspection of the exhibits all of the afternoon technical sessions were held at the exposition hall.

A number of very satisfactory local meetings were held throughout the country during the year. The most successful were meetings sponsored by your local sections in cooperation with such affiliated technical organizations as were specially interested in the particular phase of welding se-

lected for discussion. Your national Committee on Meetings and Papers assisted by suggesting authors and topics, and whenever possible by personal attendance.

Sections—The number of local sections (13) remains the same as a year ago. Interest in the older eastern and central districts was well maintained, while new and promising activity appeared at points further West and on the Pacific Coast. Efforts made to form new sections in two cities in the mid-continent region point to hopeful results during the coming year. It may be advisable to reorganize one existing section on account of the excessive distance separating its principal constituents.

Annual Exposition — In previous years, at Detroit and Philadelphia, the policy was adopted of fixing the time and place of your Fall Meeting so as to coincide with the Metal Week sponsored by the American Society for Steel Treating, thereby permitting the joint use of exhibit space and facilities by the members of participating societies. This policy was successfully continued at the 1929 Fall Meeting in Cleveland, where your industry was represented by 29 exhibitors of welding and cutting equipment. A similar arrangement has been made in connection with your 1930 Fall Meeting to be held in Chicago.

Society Committees — During the year three committees completed the work undertaken by them and have been discharged. They covered Standardization of Gages, Revision of Gas Welding Manual, and Establishment of a Miller Memorial Medal.

Six new committees have been appointed to cover the following assignments:

Specifications for Qualification Tests for Welders.

Possibility of Establishing Student Chapters.

Exposition Matters.

Welding in Marine Construction.

Administration of Miller Memorial Medal.

Publicity in the Field of Structural Steel Welding.

An innovation was made in connection with the committee on Specifications for Qualifying Tests for Welders, in that the headquarters of this committee is in Chicago and the majority of its members are located in the Middle West. Progress reports indicate that this expression of confidence in the ability of outlying members was not misplaced. The committee appointed to report on Exposition Matters is composed exclusively of manufacturers' representatives.

Four committees whose work was reported a year ago have been continued. These cover welding from the standpoint of:

Nomenclature, Definitions and Symbols.

Recommended Procedure for Pressure Vessels.

Code for Pressure Piping.

Building Codes.

The Nomenclature report was published in the November, 1929, issue of the JOURNAL, and also as a separate pamphlet. While being admittedly tentative, this notable attempt to crystallize and unify welding terms has already been widely accepted as standard.

The Welding Procedure for Pressure Vessels was prepared at the request of the A.S.M.E. Boiler Code Committee, who had it published in the January, 1930, issue of *Mechanical Engineering*. Information at hand indicates that the Procedure meets with general approval, and that an upward revision of the welding rules in the Unfired Pressure Vessel Code, based on this Procedure, will be issued by the Boiler Code Committee at an early date. The separate publication by your Society of the Procedure in the form of a welding code is contemplated. The committee which has so diligently handled this matter is to be congratulated on the larger field for welding that may be expected as a result of its efforts.

The Welding Code for Pressure Piping was prepared at the request of an American Standards Association body dealing with the whole subject of Pressure Piping. It represents a large amount of careful study in an important field. In view of the delay which might occur if the publication of this welding code had to await the settlement of other phases of the subject, consideration is being given to the propriety of now publishing it as one of your Society codes.

A year ago the Committee on Building Codes had completed the first part of its recommended Code

for Fusion Welding and Gas Cutting in Building Construction. This part, which covers Structural Steel, was published last summer in the JOURNAL and also as a separate pamphlet. The demand for the pamphlet was so heavy that it had to be reprinted. The committee has now completed the draft for a second edition in which a few matters of wording are clarified, and has added a digest of references in the code to other publications so as to facilitate its use. Work on the second and third parts of the code, covering respectively low pressure tankage and piping will now be undertaken. The compilation and periodical publishing of statistics, showing the extent to which structural welding has been used, is another of the Committee's activities. A first report of this kind was published in the JOURNAL last winter. While the work so far undertaken has done much toward securing the admission of welding into municipal codes, there is evidence of the need of further authoritative data before the process is generally accepted. What seems to be needed is a Handbook of Structural Welding Design, supplemented by a set of Typical Details showing forms of welded connection that have proved to be satisfactory in actual use.

American Bureau of Welding—The relation of the American Bureau of Welding to the American Welding Society is that of investigator to user. The Bureau tells why; the Society considers how. Incidentally, however, the research work done under the auspices of the Bureau is a stimulus toward practical extensions of welding. In recent years many of the investigations fostered by the Bureau have been made by professors at the technical schools of our colleges, with the aid of senior and post-graduate students. Such work is of the greatest value, not only as regards the new information disclosed, but possibly to an even greater degree in the interest developed among the students, for they are the ones who will later be the producers, designers and users of welding equipment and the objects made possible by its employment. During the past year the Bureau carried on its work through the medium of six committees which cover:

Standard Tests for Welds.
Structural Steel.
Rail Joints.
Pressure Vessels.
Welding Wire.
Fundamental Research.

The Committee considering the subject of Standard Tests has discussed proposals for modifying the form of specimens to be used for tensile and bend tests, but it is not yet ready to report.

The Structural Steel Welding Committee has made good progress. All of the funds pledged for its program are in hand. Practically all the tests for qualifying welders at the fabricating shops have been completed, and more than half of the program specimens have been welded and tested. Since Jan. 1, 1930, the full-time services of a technical assistant have been employed in the analysis and tabulation of the test results.

The Committee on Welded Rail Joints has completed its investigations, including the effect of preheating and postheating. It is preparing another progress report and is considering a final report in which conclusions will, if possible, be summarized.

The Committee on Pressure Vessels has considered and answered a number of specific questions referred to it by the Boiler Code Committee through your Society. The consideration of special applications, as in the case of lighter gage tanks, may require additional research.

The Committee on Welding Wire is considering the making of a statistical survey from which the need, or otherwise, of additional research may be determined.

The Committee on Fundamental Research has been quite active. It will be recalled that in 1928 it arranged a conference of the technical professors cooperating in various investigations, who met during the Fall Meeting in Philadelphia. The success of this symposium led to arrangements for a similar conference during the 1929 Fall Meeting in Cleveland. A third conference is planned in connection with the 1930 Fall Meeting in Chicago. Five reports on research topics sponsored by this committee have appeared in the September, 1929; December, 1929; and March, 1930, issues of the JOURNAL. The cooperation of additional technical schools could be utilized with advantage.

Representation in Other Organizations—At the request of other organ-

izations in which welding plays a part, representatives of your Society have been appointed from time to time to cooperate in matters pertaining to welding. During the past year the Society has participated by such representation in the following activities:

A.S.M.E. Fiftieth Anniversary Celebration.

A.S.M.E. Boiler Code Committee—Conference Committee; Code for Pressure Vessels.

A.S.T.M.—Specifications for Weldable Steel; Wrought Copper and Copper Alloys.

A.S.C.E.—Paper for International Congress at Liége in 1930.

A.S.S.T.—Recommended Practice; Joint Exposition.

A.E.R.E.A.—Specifications for Welding Rods.

A.S.A.—Electrical Definitions; Electric Welding; Standardization of Resistance Welding Dies; Safety Code for High Pressure Piping.

World Engineering Congress—Paper on Welding presented at Tokio in 1929.

Chicago World's Fair—Plans for Scientific Exhibit in 1933.

Plumbing and Heating Bureau—Text for Welding Schools.

Merchants' Association, New York.—Revision of Building Code.

National Board of Boiler and Pressure Vessel Inspectors—Executive Board.

Cleveland Engineering Society—50th Anniversary Celebration.

National Research Council—Division of Engineering and Industrial Research.

Space will not permit detailed reference to be made to all of the forenamed activities. Of special note, however, is the work of the Conference Committee which cooperates with the Boiler Code Committee of the A.S.M.E. in formulating replies to inquiries regarding the detailed application of welding under the Boiler Code. During the past year this Conference Committee acted on 13 such questions, and also gave similar advice regarding 5 questions on welding matters, not subject to the Boiler Code, that came to your Society officials direct.

Recommendation—Upon retiring I would submit the recommendation that at an early date a revision of the by-laws of the Society be considered. In my opinion, a most needed revision is in connection with membership classification. The number of different classes of membership is excessive, and the qualifications for each class are not in keeping with present conditions. Such other revisions as will keep pace with the growth of the Society should also be made.

Conclusion—It is with regret that I close the two years of office with which you have honored me. The Society is in a prosperous condition. No one realizes better than I that this prosperity is not due to my efforts or to those of any one individual. It is a natural accompaniment of increased interest in the various phases of welding and cutting. It is largely the result of good seed well sown during the early years of the Society, under the leadership of my predecessors. It reflects the creative ability of C. A. Adams, the breadth of view of J. H. Deppeler, the profound knowledge and inspiring personality of the late S. W. Miller, the financial touch of C. A. McCune, the practical standpoint of T. F. Barton, the educational insistence of E. H. Ewertz, the publicity contacts of A. G. Oehler, and the coordinating genius of F. M. Farmer.

It is due to the cooperation of every member of the Society who in official or private capacity has responded so readily and so largely whenever called upon. It is in no small measure a result of faithful and intelligent work by your salaried officials and their clerical assistants. To each and all of these I tender my thanks for the full cooperation they have rendered, as well as for their leniency in condoning my many shortcomings. I wish the Society a continuance of prosperity throughout the coming years.

Respectfully submitted,
F. T. LLEWELLYN,
President.

Technicians to Society

(*Reprinted from April 12, 1930, issue of "Electrical World"*)

This week has been characterized by the celebration of the fiftieth anniversary of the founding of the American Society of Mechanical Engineers—one of the foremost professional organizations in the technological field. The spirit of the celebration was not one of self-commendation and self-

congratulation. It partook of a review of past accomplishments, honor to those who were responsible for them and a survey of the possibilities and obligations of the future. It was a time to restate ideals and to strengthen the program for carrying out the purposes of the organization.

The future in all the technical fields is secure from a technological point of view. Competent men will bring order in the control of the forces of nature without waste in human or other material. The physical and tangible accomplishments of efficient groups of engineers working in technological fields can be predicted with accuracy. But the soul of the profession must be expressed through service to society. It is the paramount duty of a professional society to inculcate a spirit of large social significance in the minds of the members. The ideal of the engineer is to give man more complete control over his destiny and environment through the application of scientific knowledge. Progress must be social as well as technical, and, as never before, technical problems are associated with humanitarian, economic and political factors that must be considered integral parts of the engineering equations. In modern engineering obligation ranks equally with opportunity.

Recognition that engineers are technicians to society was evident in the A.S.M.E. commemoration celebrations. The spirit of service and a full realization of the social obligations of engineers inspire the society today and will make its future even more notable than has been its past.

C. A. Adams Honored

Prof. C. A. Adams, first President of the American Welding Society, and Director of the American Bureau of Welding, has received one of the highest honors that can be bestowed upon any scientist through his recent election as a member of the Engineering Section of the National Academy of Sciences.

This Section includes 20 other eminent engineers, as follows:

J. J. Carty	J. R. Freeman
Gano Dunn	Herbert Hoover
W. F. Durand	William Hovgaard
T. A. Edison	F. B. Jewett
W. LeRoy Emmet	A. E. Kennelly
C. F. Kettering	G. O. Squier
Ralph Modjeski	L. B. Stillwell
H. J. Ryan	G. F. Swain
Albert Sauveur	Ambrose Swasey
E. A. Sperry	D. W. Taylor

Professor Adams is Lawrence Professor at Harvard University and is recognized as one of the leaders in the American engineering profession. Among the honors conferred upon him were the Samuel Wylie Miller Medal for 1927, the presidency of the American Institute of Electrical Engineers, the chairmanship of the John Fritz Medal Board, the chairmanship of the Edison Medal Board, the chairmanship of the General Engineering Committee of the Council of National Defense during the war, the chairmanship of the Engineering Division of the National Research Council and first chairman of the American Engineering Standards Committee. He was, also, chairman of the Welding Committee of the Emergency Committee during the war and was responsible for the movement which resulted in the organization of the American Welding Society in 1918.

In Memoriam

On March 24, 1930 Professor Dr. J. H. Vogel died at the age of 68 in Berlin.

Prof. Vogel was one of the foremost authorities on acetylene, and his book on acetylene has been a standard for anybody interested in this gas for lighting and welding.

Prof. Vogel had always been an enthusiastic leader in the acetylene field. Largely through his efforts, unduly restrictive legislations against the use of acetylene generators were removed. He was also editor of the "Autogene Metalbearbeitung."

Clearness in Welding Drawings

(Reprinted from April 17, 1930, issue, Engineering News-Record)

By custom and necessity, standard symbols constitute the language of engineering drawings. Shorelines of rivers and lakes are designated by symbolic ripples. Sand is shown by dots, grass by sprouting clumps of short dashes. On drawings of steel structures, the rivet is denoted by one of various standard symbols expressing the way in which it is to be used—shop-driven, field-driven, coun-

tersunk near or far side—and the result is so clear that no explanatory notes are required. With the advent of welding a need arose for a new symbolic language. But it was a need that was not officially recognized for a number of years, with the result that each individual shop devised its own nomenclature. When welding developed a rapid growth and structural welding entered the field, this lack of standardization proved a disadvantage. Now, a committee of the American Welding Society has worked out a set of symbols that can do much to remedy the situation. The recommendations of this committee should be embraced by every designer and shop craftsman to the end that welding drawings may become in some measure standardized and brought to the same degree of clearness that characterizes topographical and geological maps and riveted structural steel drawings. Also, such use will assist in revealing at an early date any lack of adequacy in the recommended symbols.

SECTION ACTIVITIES

CHICAGO

J. H. Babcock, general foreman of the Barber-Greene Company, Aurora, Ill., manufacturers of material handling equipment, was the speaker at the April meeting of the Chicago Section of the American Welding Society, which was held Thursday evening, April 3, in the lecture room of the Greer College of Automotive Engineering.

Mr. Babcock's subject was "Electric Welding and Economy," and his talk was centered around the many applications that his company has made of arc welding in fabrication of their products. He pointed out that their first use of the process was only in a small way and of an experimental nature and that these first trials pointed out so conclusively the many economies that could be made by using arc welding that more and more their equipment is being redesigned to take advantage of these economies.

His talk was illustrated with lantern slides, which showed many of the items which he mentioned in his talk.

The May meeting of the Chicago Section was held on the 8th in the Thirty-ninth and Racine Avenue plant of the Air Reduction Sales Company, where a very interesting paper, "Multiple Plate Cutting," was presented by Richard Helmkamp of the Air Reduction Sales Company. Mr. Helmkamp has made a considerable study of the subject of cutting comparatively thin plates several at a time.

Following the presentation and discussion, Mr. Helmkamp demonstrated the operation in which he cut 12 thin sheets, stacked together, with the oxygraph.

This is the last meeting of the Section until next fall.

CLEVELAND

An attempt is being made by the officers of the Cleveland Section to arouse the interest of the members of the Section in its activities. This effort deserves the cooperation of everyone concerned.

LOS ANGELES

The April meeting of the Los Angeles Section held on the 14th was a very successful one, there being 242 members and guests present.

This was a joint meeting with the American Society of Steel Treaters.

Dinner was served at 6.30 p. m. at the New Paris Inn, after which the meeting was called to order.

W. A. F. Millinger, chairman of the Los Angeles Section, gave a short talk on "Prosperity."

Miles Smith, of the Stoody Company, gave a talk on "What Is Being Done in Examining Welds with the Spectroscope."

Edward Kottmauer gave a talk on "Trouble Shooting in the Alloy Steel Mills."

PHILADELPHIA

The Philadelphia Section will hold its May meeting on the 19th. W. B. Miller, of the Union Carbide and Carbon Research Laboratories, will talk on "Oxy-Acetylene Welding of Commercial Chromium Alloys," and R. D. Thomas, of R. D. Thomas & Co., will tell about "Arc Welding of

Stainless and Corrosion-Resistant Steels."

SAN FRANCISCO

The April meeting of the San Francisco Section was held on the 25th.

Four men spoke on the topic "Qualification and Training of Welders."

Lieut. Commander H. M. Wallin, U. S. N., from the Mare Island Navy Yard; Mike Fisher, of the Standard Oil Company Richmond Refinery; W. J. Moriarity, foreman welder for the Southern Pacific Company, and W. P. Brown, of Brown Brothers Welding Works, all gave their views on this important subject.

SOME OF THE CONTRIBUTORS TO THIS ISSUE

Lee H. Miller, chief engineer of the American Institute of Steel Construction, author of the paper on the Battledeck Floor Construction, has been actively identified with structural steel work for more than 25 years, was born Jan. 25, 1877, and was graduated from Toronto University in 1900. He was associated with such companies as the Brown Hoisting Machinery Company, The Wellman-Seaver Engineering Co. and The McMyler Company, during which time he was engaged in estimating and designing structural steel for cranes, bridges and buildings. He was also connected with the Bethlehem Steel Company as structural sales agent. Since 1922 he has been connected with the work of the organization of the American Institute of Steel Construction.

William F. McKay, author of the paper on "The Needs of the Metropolitan District for Instruction in Welding," was born in 1889. He is connected with the International Oxygen Company as its chief engineer and in this capacity has been in charge of the design, installation and operation of oxygen, hydrogen and acetylene plants. He is a member of numerous technical committees of the Gas Products Association, the International Acetylene Association, and is, also, a member of the American Welding Society. He also assisted A. A. Heller in the design of oxygen and acetylene plants for Russia.

Employment Service Bulletin

SERVICES AVAILABLE

A-96. Welder desires position. Have had 6 years' experience in electric welding, also acetylene and cutting, on tanks, boilers and conveying work.

A-97. Engineer thoroughly well trained in the design of structural steel and ornamental iron from the arc welding standpoint. Will furnish references.

A-98. Have had 10 years' practical experience in all lines of welding, and know applications in the railroad industry. In addition to this, was sales engineer and have had experience in a research laboratory.

A-99. Instructor in welding desires position. Have had 12 years' experience with all processes of welding including work on pressure boilers, locomotive frames, pipe work, tanks, structural steel, light gage metal, smoke stacks. Have been employed with a number of large companies, including Pennsylvania Railroad, Linde Air Products Co., Whittenmyer Machine Company. Can furnish references. Have taken course in night school conducted by State College. Am employed at present.

A-100. Foreman desires position. Am 30 years of age, married. Have high school education. Training in modern foremanship at Pennsylvania State College. Have had 10 years' welding experience in the field; 6 years as foreman. Inventor of process for welding corrosion-resisting alloys. Experience on high pressure valves and fittings, steel castings for railroad, jigs and fixtures, maintenance and repair work. Am also expert welder and can instruct welders.

Welded Steel Floor Construction*

LEE H. MILLER†

IT is probable that the most important single accomplishment of the human race has been the attainment of a temperature that would melt large steel ingots on an economically commercial basis. This was accomplished somewhere in the neighborhood of 1880 and since that time there has been a greater change in the economic, industrial and scientific phases of human endeavor than all the rest of history combined. In fact it can be safely stated that our progress has been inversely proportional to the cost per pound of steel.

Last June in addressing the graduating class of Western Reserve University the speaker stated that 90 per cent of the human knowledge has been acquired in the last fifty years. Even if this statement were discounted 50 per cent it is still startling. Since that time every phase of our existence has been completely revolutionized or is still passing through such a condition, and all of it can be traced to the basic influence of steel on all other interests. During such a period of revolution it is natural that many false starts and experimental undertakings would come into existence, and be subjected to the conservative attitude of those who are more influenced by the traditions of the past than the expectations of the future.

The basic requirements of existence are food, housing, and clothes. In connection with the problem of housing, steel has in the last fifty years, in the United States, been instrumental in developing a genius for architecture that has resulted in the most remarkable type of building construction that the race has ever known. Even in the last five years it is easy to detect a transition in the nature of our skyscrapers and the introduction of architectural treatment that never existed before.

The sole purpose for constructing a building is to provide floors which can be protected from the weather by walls, windows and roof covering. The only reason for building a floor is to provide support for a live load. The floor of a building may be the ground itself, but it is usually a more intimate part of the structure.

When the skyscraper came into existence it provided multiple tiers of floors, one above the other supported on a steel skeleton frame consisting of steel columns, girders and beams. At that time the skeleton frame provided sufficient tonnage to satisfy the productive capacity of the steel mills, and the problem of installing floors in the panels between the main girders was left to the architect and the engineer. Originally these floors were made of brick arches, later of flat tile arches, and still later of other

*Paper presented at Annual Meeting, A.W.S., April, 1930.
†Chief Engineer, American Institute of Steel Construction, Inc.

types of material such as wood packed floors, reinforced concrete and gypsum.

At the inception of the multiple story building the art of welding as it now exists was unknown, but progress in this field has made it possible to develop a type of steel floor which will meet every requirement that floor construction is called upon to perform.

Probably no part of a building structure under present conditions has been more unsatisfactorily developed than the floor panel construction, and yet it is the one reason for having a building. Present methods of construction involve the use of materials in the floor panels which constitute a dead load that generally weighs considerably more than the live load which is to be supported. This excessive weight of the floor

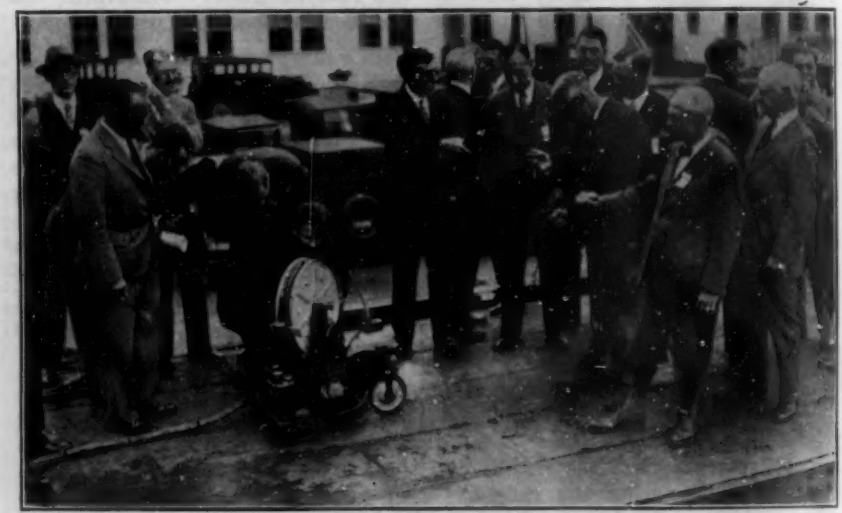


FIG. 1—AUTOMATIC MACHINE DEVELOPED FOR WELDING BATTLEDECK FLOOR CONSTRUCTION. DEMONSTRATION AT ANNUAL CONVENTION, A. I. S. C.

panel must be carried into the skeleton frame, girders and columns, and ultimately to the foundation. It is therefore evident that one of the conditions which limits the height of multiple story buildings will be the capacity of the foundations to carry the dead load of the structure, which is greater than the calculated live load.

Reference to the column schedule of a multiple story building will show that the column stresses for dead loads are often approximately two-thirds the total stress, the other third being live load.

Engineering practice and code requirements recognize that the probability of the contemplated live loads being simultaneously applied to all floors of a building is very remote, and therefore it is permissible to assume a very substantial reduction in the specified live load for designing the lower story columns and foundations of tall buildings. This per-

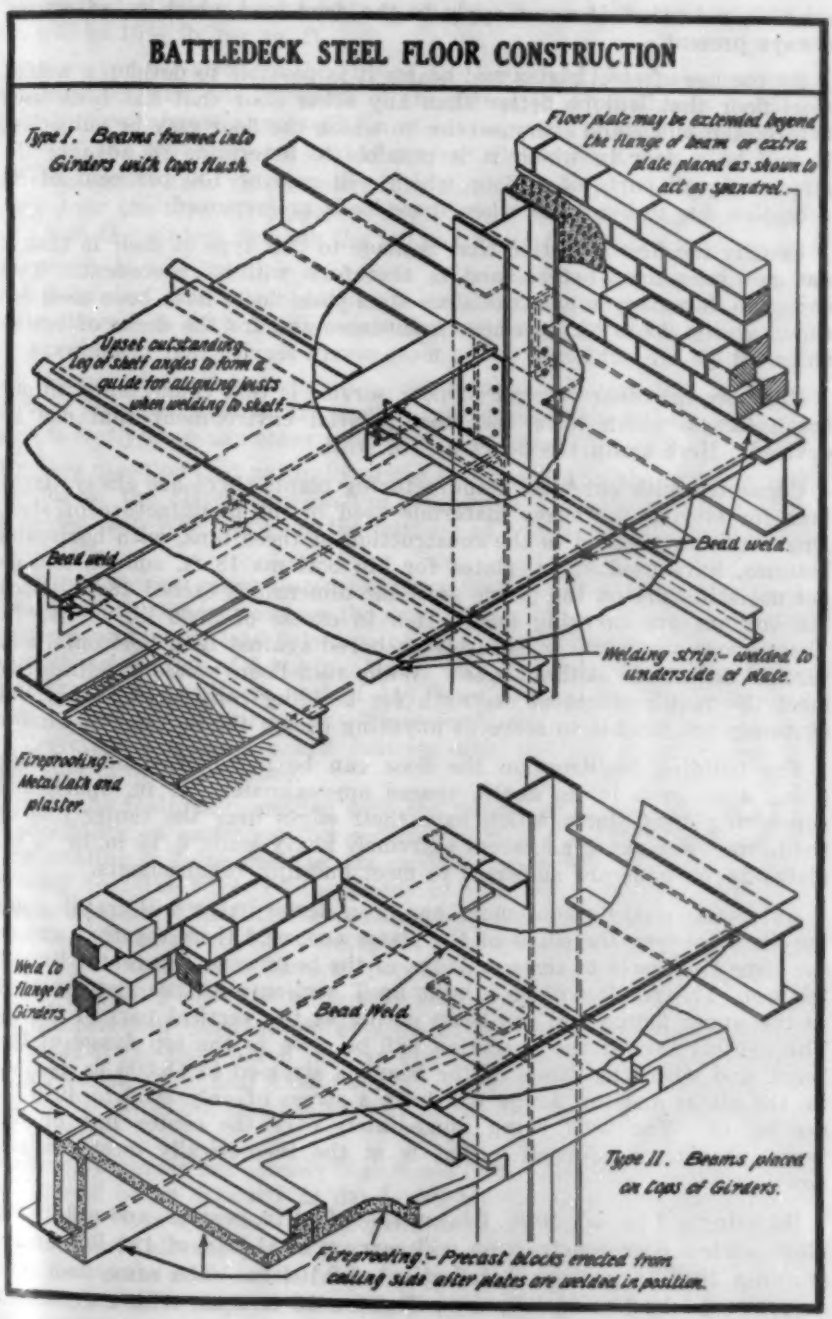

BATTLEDECK STEEL FLOOR CONSTRUCTION
Type I. Beams framed into Girders with tops flush.
Floor plate may be extended beyond the flange of beam or extra plate placed as shown to act as spandrel.
Upset outstanding leg of shelf angles to form a guide for aligning joists when welding to shelf.
Bead weld.
Bead weld.
Welding strip:- welded to underside of plate.
Fireproofing:- Metal lath and plaster.
Weld to flange of Girders.
Bead Weld.
Type II. Beams placed on tops of Girders.
Fireproofing:- Precast blocks erected from ceiling side after plates are welded in position.

FIG. 2

missible reduction does not apply to the dead load which is, of course, always present.

By the use of steel plates and beams it is possible to develop a welded steel floor that will be better than any other floor that has been used before, and will stand every service to which the floor may be subjected. It will be a floor in which it is possible to determine in advance the stresses in all parts of a floor which will recover 100 per cent of its deflection due to live loads when those loads are removed.

Usually the first objection that is made to this type of floor is that it has not been used before, and is therefore without precedent. This objection, however, is not true since steel plate floors have been used for the charging floors of open hearth furnaces and for the decks of battleships, which are subjected to the most severe service that is known.

Probably the other extreme of floor service is that connected with our ocean liners, which have the most palatial environment that can be devised. Here again the floors are of steel.

Connected with our steel manufacturing plants there are always large bins for storing the heavy materials used in the manufacture of steel. Engineers experienced in the construction of these bins, with horizontal bottoms, have used $\frac{5}{8}$ in. plates for bin bottoms 18 ft. square, and do not use stiffeners on the plates until the dimensions exceed 18 ft. Such bin bottoms are carrying loads often in excess of 3000 lb. per sq. ft. These floors are, however, securely anchored against both horizontal and vertical deflections at their edges. While such floors would satisfactorily meet the requirements of strength for building construction, they are obviously too flexible to serve as anything except the bottoms of bins.

For building construction the floor can be made of small I beams 3 in., 4 in. or 5 in. in depth, spaced approximately 24 in. apart, and supporting steel plates which have their edges over the center line of the beam. For anything except extremely heavy loads, 3/16 in. or $\frac{1}{4}$ in. plates 24 in. wide are sufficient to meet building requirements.

Automatic welding equipment has been devised that will travel along the seam between the edges of the plates and weld them together and at the same time weld to the top flange of the beam over the center line of the web. The result will be a built up T section with the plates acting as the upper flange and the beam acting as the vertical part of the T. The neutral axis of the T section will be close to the top flange of the beam, and when the flange of the beam is stressed to 18,000 lb. per sq. in. the plates and top flange will have a stress of only 3000 to 4000 lb. per sq. in. The weld being immediately over the center line of the beam, provides a connection that is at the theoretically most efficient position.

By using a 3 in. 5-7/10 lb. I beam spaced 24 in. centers, and a 3/16 in. plate, such a floor construction will carry a total load of 190 lb. per sq. ft., on a 10 ft. span with a deflection of 0.104 in. The same floor will carry a total load of 85 lb. per sq. ft. on a 15 ft. span with a deflection of 0.235 in.

The weight of the steel work, including the beams and plates for this floor, will be 10½ lb. per sq. ft.

By a proper variation in the size of the beam and the space between them, together with the thickness of the plates, it is possible to develop a floor to meet almost any condition of loading with a dead load saving of from 25 per cent to 50 per cent of present construction.

It is assumed that this combination construction will be made continuous over the tops of the supporting girders or by framing the small beams into the girders flush on the top and having the plates continuous.

Inasmuch as any interior floor panel of a building is completely surrounded by the other floor panels, it is obvious that the calculations for the stresses in such panels can be properly based on the fact that the ends are fixed.

By the use of the flame-cutting torch or the electric arc it is possible, at a very low labor cost, to frame this floor system into irregular panels more efficiently than any other type of floor now used.

Another question that naturally arises is, what will be the strength and deflection of the plates between the supporting I beams to which they are welded, and which are for the purpose of this paper, assumed to be 24 in. apart.

A ¼ in. plate will carry a uniformly distributed load of 562 lb. and have a deflection of 0.089 in. between the small beams. These plates will carry a center concentrated load between the small beams of 750 lb. per linear foot, with a deflection of 0.119 in. Under the same conditions the 3/16 in. plate will carry a uniform load of 316 lb. per square ft., and a concentrated load of 422 lb. per sq. ft. These loads are far in excess of what the T section will develop and indicate that the floor construction is amply safe in both directions.

One of the features connected with the construction of such a floor is the possibility of getting plates sufficiently flat and free from camber. If the welding is to be done by the carbon arc method, it is, of course, necessary that the edges of the plates be as close in contact with each other as possible, and that the distance between the edges shall not be excessive. If, however, the welding is to be accomplished by the metal arc it is advantageous to have a space of approximately ¼ in. between the edges of the plates where the weld bead is deposited.

In the practical construction of some of the floors that have already been made it has been found that an excessively large weld rod requires the generation of a heat that tends to cause the plates and beams to warp out of shape, but this has been overcome by reducing the size of the weld wire.

So much progress has already been made in the art of arc welding that there should be no difficulty in developing automatic machinery to take care of this floor system. In fact, different manufacturers of welding equipment have already put on the market automatic traveling equipment that will weld the seam at the rate of approximately 90 ft. per hr., and at a cost estimated to be approximately 3c. per linear ft. These welding costs, however, are dependent on the conditions connected with the operation itself.

In construction it will be found necessary to weld the bottom flange of the I beam to the shelf angle on the main girder in order to provide continuity or a fixed end bending moment.

The actual amount of welding necessary to develop the strength of the T section is only about 25 per cent to 40 per cent of the length of the seam, but it will undoubtedly be more economical and satisfactory to make the welding continuous rather than attempt to develop the strength with the minimum amount of welding.

The floor construction itself generates a solid steel deck, which will act as a girder to prevent any twisting distortion to the building when subjected to wind or earthquake. It will enable the engineer to select that part of the structure which is to carry the wind stresses to the foundations, and be assured that the deck flooring will deliver the stresses to the most rigid part of the vertical frame. The floor construction can be carried out into the walls to provide spandrel construction to support the outside walls. It will provide a working floor for other trades and in many places eliminate the necessity of temporary planked floors.

It will, of course, be necessary to fireproof such floors when the combustible contents may generate a heat that will produce a temperature in the steel in excess of 1000° F. This fire protection can be taken care of either by metal lath and plaster or by precast blocks of fireproofing inserted or suspended on the lower flange of the small beams. Either type can be erected after the welding is completed, and there will be provided openings for conduits which may be carried along the main girders and transversely under the steel plates between the small beams. On the other hand, if it is advisable to do so, it will be possible to lay all of the conduits on the top of the steel plates, and have them covered with a light weight fill, which will also act as a top fireproofing in case it should be required.

At the present time, however, the specifications written to regulate the testing of floor construction for fire do not contemplate a fire on the upper surface. It has been assumed in the past that the fill on the top of ordinary floor panels to cover conduits acts as fireproofing for the top flange of beams and girders. On the other hand, if grate bars and furnace construction is a precedent it should be possible to have a very considerable fire on the top of the plates without the temperature becoming dangerous. This is due to the fact that all heat generated from combustion will rise, and all air necessary to feed combustion must come from the floor. The evidence that this condition actually exists in fires is borne out by a recent fire which occurred in a wood-working factory for manufacturing automobile bodies. An extremely intense fire existed immediately surrounding the automobile chassis with its rubber tires, but neither of these were destroyed, and the floor above which was considered fireproofed was completely destroyed from the heat on the ceiling side.

It is possible to provide any form of treatment for the top surface of these steel plates, either mastic finish, linoleum, cork tile or other forms of covering. A manufacturer of cork tile has stated that they recently took a contract for covering approximately 40,000 sq. ft. of floor in the Cleveland Terminal Tower Building, at a price of approximately 42 cents

a sq. ft. Such floors can be laid with a mosaic pattern in various shades of brown, and eliminates the necessity of rugs, except as ornaments. The total cost of a floor constructed of 3 in. I beams and 3/16 in. plates covered with cork tile and fire proofed on the underside will be a little more than $1 per sq. ft. It should be remembered in this connection that the cork tile floor eliminates the necessity of any other floor covering, which is always a part of the tenant's expense when using an ordinary masonry floor. The cost of a good chenille rug is from $1.25 to $1.50 per sq. ft. and the above referred to floor system will cost complete, less than the carpet, and eliminate its necessity.

Some of the large department stores of the country have found that the dusting which takes place in ordinary masonry floors has a very serious effect on their delicate fabrics, and in one instance a large department store has installed steel checker plate floors without any covering whatever, and these floors are accepted by the building department as fireproof.

The floor for the addition to the Library of Congress at Washington is designed of steel plates bolted to angles and channels with ½ in. of cork tile floor on its top surface. I have been advised that the floor will be installed by welding instead of bolting. Here is a structure requiring both quietness and fire resistance.

Several floor panels have already been constructed and the results confirm the theoretical analysis as to strength and deflection. In fact, the deflections indicate that the floor is actually stronger than the theory would indicate, based upon bending moments in the material.

For bridge floor construction a combination of steel beams with steel plates can be assembled that materially reduce the dead load of the structure, and provides a lateral rigidity more satisfactory than any floor diagonals now used. Several drawbridge spans have already been designed with this type of construction, and they have resulted in not only reducing the dead load but also the cost of the structure.

Used in connection with multiple story buildings the saving in dead load is sufficient to enable the engineer to add 25 per cent or more floors to the structure without increasing the load on the foundations.

From the standpoint of the welding equipment manufacturers and engineers, this type of floor construction offers an excellent means of promoting the general introduction of the art of welding for construction purposes. Whether we recognize it or not, there has been a very definite antagonism on the part of many engineers against the use of welded connections, but this floor system uses welding only for the development of the secondary stresses in floor panels, and provides an outlet for welding equipment and application on a scale so much greater than exists in welding the primary members of the frame together, that it should be possible to use it as the basis to overcome the general prejudice that exists against this very valuable tool.

The A. I. S. C. has prepared several pages of tabulated data, showing the allowable loads and deflections for various spans of floors constructed on this basis, and this data is available for distribution on request.

The Strength and Design of Fusion Welds for Unfired Pressure Vessels*

By L. W. Schuster

Object of the Investigation.—An investigation into fusion welding as applied to the welding of unfired pressure vessels has recently been undertaken by the author's company with a view both to their determining whether they were appraising at their true worth the legitimate claims arising from the more recent development of fusion welding, and at the same time to their endeavoring to place the application, as applied to pressure vessels, on a safe and rational basis. The findings do not in any way apply to the welding of structures other than pressure vessels.

Scope of the Investigation.—The work undertaken involved the carrying out of various mechanical tests on welds in mild steel, a limited number of tests being made on other materials used for pressure vessels; metallurgical examination to search for the causes of the variable properties of welds; observations of the various processes and practices carried out; the collection of information enabling opinion to be formed on certain controversial points, and allowing provisional rules governing the construction of pressure vessels to be framed; the studying of the results obtainable with a wide range of electrodes; the determining of the strengths of the various forms of joint used on pressure vessels; and an attempt to classify them on an efficient basis. No claim was made that the experiments were in any sense exhaustive, only the data deemed essential for immediate requirements being obtained. Visits were paid to a large number of the leading makers of electrodes and to several makers of welded vessels, and the work undertaken would have been impossible without the assistance and facilities granted by these makers during the visits.

Self-generating versus Non-fired Pressure Vessels.—The difference between the working conditions of a self-generating and a non-fired pressure vessel has been explained in the published report[1] and will not be repeated here. Among vessels at present covered by the Explosions Acts are steam-boilers and vessels in which water or other liquid is heated, or into which steam is admitted for any heating purpose. These include vessels such as fuel economizers, autoclaves, impregnators, steam separators and receivers, jacketed pans, steam-heated keirs, steam-heated presses and hot plates, and bakers' ovens.

Among vessels that come under the contemplated legislation are air-

*Extracts from a paper written by the author and presented at the March 7, 1930, meeting of the Institution of Mechanical Engineers. The paper is practically reproduced in its entirety except a few pages which cover conditions relating to the welding of pressure vessels in England.

[1] British Engine Boiler and Electrical Insurance Company, Technical Report for 1928.

receivers for starting gas- and oil-engines, for driving tools in workshops, for road construction, for paint sprayers, and for charging motor tires; for use with pneumatic brakes on electric winders, with glass-blowing machinery, and with air-lift pumps; and for use in mines for coal cutters, in building construction, and in quarries. In addition to air-receivers, the intention is presumably to include CO_2, ammonia, and other gas containers used for refrigerating plant and in bottling stores and other industries. The pressure in such vessels ranges up to 500 lb. per sq. in., or even to 1000 lb. per sq. in. for starting vessels for Diesel engines.

Limitation of the Recommendations Made.—It is not to be expected that a first set of rules could be devised to cover the whole field of pressure vessels, and the decisions reached as a result of the investigation chiefly cover the construction of vessels subjected to air or gas pressure. Any future extension can hardly be expected before vessels that they do cover are brought up to the required standard. In view of a tendency that has been noticed for certain remarks in the report to be applied to water gas welding, it should perhaps be emphasized that, though excellent pressure work has been carried out in this country by this process, not only for boiler furnaces but for certain vessels in tension, the rules and the remarks made here and in the report apply to fusion welding[1] only.

The Present Unsatisfactory Construction of Welded Vessels.—It was felt that the disfavor with which welding is regarded in many quarters was in a large measure due to the lack of control in matters of design and manufacture, and that by a regulation of the latter the former would to a large extent disappear. At the outset it might be made plain that the fact that a weld can be made with 100 per cent of the strength of the plate while a riveted seam may have only 75 per cent cannot be advanced as a serious argument in favor of welding. It begs the whole question. The prime concern is reliability.

Part I.—Mechanical Construction

Basis for, and System Adopted in Fixing Maximum Ratings.—The object was to fix the stresses that could be permitted for the various forms of joint most commonly encountered. In consideration of existing Board of Trade regulations and of the fact that these fix a maximum efficiency of 50 per cent for a forge-welded joint in compression, any practices extant abroad were found useless for the purpose of a basis.

In the past it has been customary to express the strength of a fusion-welded butt joint as a percentage of the plate strength. This is a practice originating with fire welds, where it is clearly, as with gas or resistance welds also, a very suitable method of rating. With fusion welds the method is, from the point of view of the manufacturer, useful for testing the relative skill of individuals, when all the welds are of the same form and are made under identical conditions, but the information is lacking in absolute value when these conditions do not hold.

The strength of a weld expressed as a percentage of the plate strength, with the conditions undefined, is in itself neither a measure of bad work-

[1] Editor's Note: Arc and Oxy-Acetylene Welding.

manship, nor of the quality of the weld metal. The relationship is dependent not only on both of these factors combined but on the relationship between the composition of the weld metal and the plate. With fusion welds there is no difficulty on the one hand in obtaining metal stronger than the plate, nor on the other in making a first-class weld that is weaker than the plate. It was felt therefore that a general assessment of the strength of a joint of a particular form could not be effected by using the plate strength as a standard of comparison and that a more rational method of comparing welds of different forms was to use as a standard some typical form of weld, made under identical conditions.

It was considered that the most convenient manner of expressing the strength of a joint of particular form was as a percentage, described as the "joint efficiency," of a single-V butt weld made on *similar material with the same welding rod by the same operator, the surfaces of the butt weld being machined down to the level of the plate.* As the strength of a reasonably well-made butt weld, made with a given welding rod under a given set of conditions, is generally a known quantity, or when not known may easily be ascertained, the joint efficiencies give immediately, without an elaborate series of tests, the absolute strength of a range of joints made with any welding rod.

As it is standard practice for the strength of plates for steel vessels to be within the limits adopted for boiler construction, and as ductility, which is always of the highest importance with a vessel subjected to fluctuations of pressure, becomes of more importance with a plate that is liable to be injured either structurally or mechanically by the heat of fusion welding, it was decided that the most suitable standard was the lower limit of the welding-quality boiler plate, i.e., 26 tons per sq. in. ultimate strength. For comparative purposes it might be mentioned that a maximum carbon content of 0.12 per cent is recommended in Switzerland, when the plate is to be either electric-arc or oxy-acetylene welded and is to be used in pressure vessels; the equivalent strength of this is round about 26 tons per sq. in.

As a firebox quality plate can never be rated at more than 26 tons per sq. in. and there is always the danger of the surfaces being undercut, it was decided that the maximum strength of a welded plate should never be considered to exceed 24 tons per sq. in. As there is no reason why, with a sound weld, this low figure should not be obtained with any suitable welding rod, it was adopted as furnishing a figure pre-eminently suitable for the purpose in view, i.e., general application. As it obviously would be inconsistent to rate a butt weld at 24 tons per sq. in. and to rate any other form of weld on its actual strength, a natural basis for rating a particular form of joint was found to be 24 tons per sq. in. multiplied by the joint efficiency, expressed as a fraction.

In view of the Board of Trade rule, already referred to, fixing a maximum efficiency of 50 per cent for a hammered weld, it was deemed inexpedient to assess the strength of any form of joint in a pressure vessel at more than half the basis value, the value so found being described as the rated strength. The maximum stress permitted in any joint of a pressure vessel is therefore the rated stress divided by the required

factor of safety. It is to be noticed that, if a factor of safety of 4 is applied to the rated strength of a butt weld, i.e., 12 tons per sq. in., the maximum permissible stress in the joint is 3 tons per sq. in. This compares with 2½ tons per sq. in.* allowed in America by the American Society of Mechanical Engineers' code. The Swiss Steam Users allow a higher stress, which varies according to the type of weld.

Though the permissible strength is slightly higher than that officially adopted in America, it is doubtless disappointingly low to manufacturers in this country. Nevertheless it is difficult to see how with consistency the ratings can be increased while the rating generally adopted is only 13 tons per sq. in. for a rolled water-gas weld, where there is no difficulty in ascertaining the name of the maker and the full details of the process, and where a weld made by a reputable maker can be reckoned with certainty to yield 90 per cent of the plate strength. For a general rating of fusion welds, where the details of manufacture are less defined, it would be totally illogical to fix a higher rating figure than that given.

Joint Efficiencies Determined by Test.—With any form of joint, whatever the form of construction, it is of course impossible for the overall strength to exceed that of the plate. With welds, however, where the strength is assumed to be only half the actual value, there is a distinctly usful purpose attached to the use of a compound joint with a combined strength considerably greater than that of the plate. This of course applies only when the various components of the joint can be relied upon to carry their fair share of the load, when subjected to the actual conditions of work. It has therefore been considered legitimate to name weld efficiencies at figures higher than 100 per cent, while to obtain such high figures on test has naturally involved the use of specially designed test strips.

Table 1 indicates some of the efficiencies obtained. It cannot be too strongly emphasized that these efficiencies apply to a tensile test only, and it by no means follows that the useful strength of the welds, when forming part of a joint in a pressure vessel, bears any relation to the figures given; in fact some of the joints could not be expected to withstand pressure at all.

It is only to be expected that random tests may yield figures very different from those given here. There are several reasons for this. With fillet welds enormous variations will occur if the fusion is not good at the inner corner. Likewise greater strengths can be obtained by deep penetration of the weld metal at the inner corner of fillets, by thickening up the fillets, or by adopting an incorrect design of test strip that relieves a weld of bending or other stress. A great amount of work was involved in preparing the specimens and rectifying the width and contour of fillets. All the specimens had to be etched during preparation, some of them several times.

The efficiencies given are based on the figures from several hundreds of tests and are the result of a thorough analysis of the figures obtained.

*A stress of 3½ tons per sq. in. is at present being contemplated, as long as the recommended procedure is complied with.

TABLE 1.—*Relative Strengths of Various Forms of Joint.*

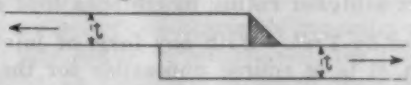
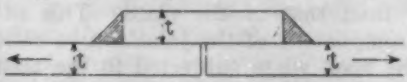
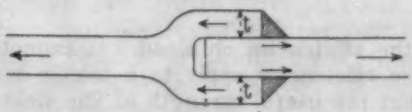
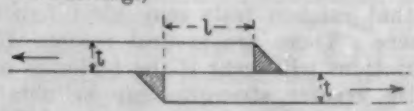
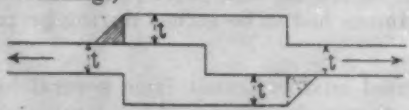
No. of Joint.	Form of Joint.	Test η, per cent.	Remarks.
1	Non-reinforced butt weld.	100	—
2	Lap weld with single fillet (Subjected to bending.) 	50	Up to $\frac{1}{2}$-inch plate for circular seams. Quite unsuited for longitudinal seams of pressure vessels.
3	Single butt strap. 	50	Ditto.
4	Lap weld. (No bending.) 	60	This is equivalent to a lap-welded circumferential seam, of which the flexure is neglected.
5	Lap weld with two fillets. (Subjected to bending.) 	100	l not less than $3t$. Only suitable for longitudinal seams of pressure vessels when t does not exceed $\frac{3}{4}$-inch.
6	Half-lap joint with two fillets. (No bending.) 	120	Not suited for longitudinal seams of pressure vessels.

TABLE 1.—*continued.*

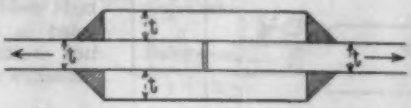
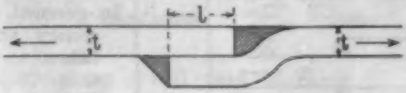
No. of Joint.	Form of Joint.	Test η, per cent.	Remarks.
7	Double butt straps. 	120	Ditto.
8	Joggled lap joint. 	133	l not less than $2t$. Only suitable for longitudinal seams of pressure vessels when t does not exceed $\frac{3}{8}$-inch.
9	Joggled lap joint.	133	Ditto.
10	Butt weld with single strap of half the plate thickness.	—	An unsatisfactory form of joint. Bending stresses are introduced and complex stresses set up at the fillet welds, with the result that the strap only increases the strength of the joint inappreciably above that of a plain butt weld.
11	Butt weld with single strap of full plate thickness.	120	An unsatisfactory form of joint; not recommended for pressure vessels.

TABLE 1.—*continued.*

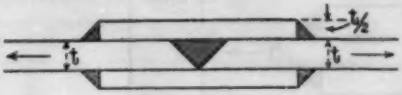
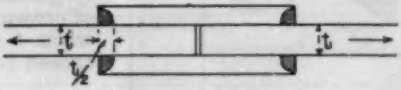
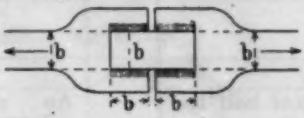
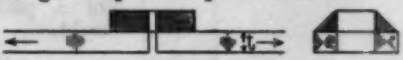
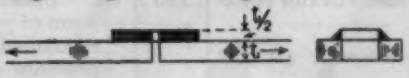
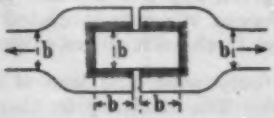
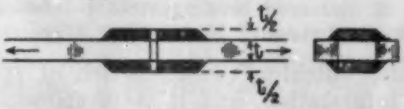
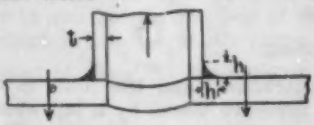
No. of Joint.	Form of Joint.	Test η, per cent.	Remarks.
12	Butt weld with double straps of half the plate thickness. 	160	Straps prevent inspection of the butt weld, and the joint is therefore not suitable for pressure vessels.
13	Special form of lap joint. Weld metal in shear. 	80	Ditto. In general, the efficiency should be taken not higher than 70 per cent. This joint shows the efficiency of weld metal in shear.
	Transverse cover straps, welded at the sides only. 		The strength depends on the form of fillet and in general fracture takes place at the place indicated below.
14	Double straps of half the plate thickness, opposite one another.	90	The strength of the weld per unit length is 75 per cent that of a lap weld at the end of the strap.
15	Single strap of full plate thickness. 	75	
16	Single strap of half the plate thickness. 	45	The result is relatively higher than before, owing to the strap receiving greater support against bending.

TABLE 1.—*concluded.*

No. of Joint.	Form of Joint.	Test η, per cent.	Remarks.
	Transverse cover straps welded at all sides. 		
17	Double straps of half the plate thickness, opposite one another. 	150	—
18	Single strap of full plate thickness.	125	—
19	Welded flanges.	—	*See* Fig. 8.
20	Branches and other fittings affixed by a fillet weld. 	$\frac{50h}{t}$	Provided that the wall of the main tube is rigid. For minimum requirements *see* pages 40 *et seq.*

Owing to the variations inevitable with welds, no claim is made of infallibility, but the figures are given with every confidence that they furnish with sufficient accuracy for the purpose the tensile strength of reasonably well-made welds in plates varying between ¼-in. and 1 in. in thickness. The figure should be studied in conjunction with the following explanatory notes:

(1) The efficiencies compare the strength of joints in members of thickness t with the strength a member has when butt-welded, without reinforcement.

(2) The efficiencies refer to joints of the same width as the plate.

(3) With fillet welds the efficiencies apply when the fillets have an approximately straight contour, lying at 45 deg. with the surfaces of the plate. The efficiencies also apply to other contours so long as the throat thickness is not less than $0.69t$.

(4) A joint may readily be made stronger than the body of the plate outside the joint. As the efficiency refers to the joint itself and not to the plate, it follows that a higher efficiency than 100 per cent can readily be obtained. It has been possible to record efficiencies where they exceed 100 per cent, by the adoption of specially designed test-pieces.

(5) It must not be inferred that all the joints shown are permissible for pressure vessels; the figures given apply to a static tensile test, and it does not follow that the behavior of joints subjected to the stresses of service will be in proportion to the efficiencies given.

(6) The strengths given are valid only when the load is applied in the manner shown in the sketches. The efficiency is, therefore, in some instances superior (on account of reduced bending stress) with a similar joint at the circumferential seam of a pressure vessel, and sometimes (on account of increased bending stress) inferior with a similar joint at a longitudinal seam.

In carrying out tensile tests, watching the distortion of specimens during fracture gives useful information, and it is recommended that the load at which the first crack is set up should be recorded.

Brief remarks in regard to the forms of joint shown are given below, and further explanatory matter is given at a later stage.

Joint 1. No appreciable difference in strength was found with various forms of "V," provided that there was no flaw, either at the surfaces or junctions, or at the center of a double V. A single V joint welded from one side of the plate only is highly undesirable and can only be accepted at a nominal value.

Joint 2. With a well-made weld the behavior under steady tensile stress was remarkably good, in spite of the severe bending stress. The weld is totally unfitted for fluctuating stresses and is not permissible for longitudinal seams of pressure vessels.

Joint 3. Very similar to the preceding.

Joint 4. The bending action is neutralized, and the joint is equivalent to that on a rigid end affixed to a pressure vessel by a lap weld.

Joint 5. The greatest care should be adopted in fitting the plates. The joint is ill-adapted for the longitudinal seam of a pressure vessel, owing to the load being unevenly distributed between the two fillets; it is only permitted for longitudinal seams when the plate is thin, and then only at a greatly reduced rating.

Joints 6 and 7. These are shown more for theoretical than practical purposes. Accurate bedding of the parts would be a prime essential with joints in pressure vessels constructed thus. For longitudinal seams these joints would be looked upon with extreme disfavor on account of the readiness with which a crack in a fillet, when once formed, could develop along the whole length of the vessel.

Joints 8 and 9. These are also inserted mainly on theoretical grounds. They are not in use on pressure vessels and would only be permitted at all where the workmanship is beyond doubt, i.e., when the plate has not been thinned while being set and the components have been accurately bedded to each other. When the joints are well made and the load is in pure tension they certainly yield high strength, but, like lap welds with

two fillets, their use for longitudinal seams could only be limited to thin plates.

Joint 10. Though an appreciably higher strength is sometimes obtained with this form of joint than with a butt weld, the gain has been found of doubtful value. The joint is objectionable not only on account of the bending stress introduced by the strap, but because the strap prevents inspection at one side of the butt weld. Even with the strap plug-welded to the plate, the joint is undesirable for pressure vessels.

Joint 11. The same remarks apply to this joint. The efficiency named is given as affording general information only.

Joint 12. Though the bending action is almost neutralized here, the main joint is not accessible at either side for inspection, and with pressure vessels no credit can be given for the hidden butt weld; the joint if used would, therefore, only be credited with an efficiency of 120 per cent. At any rate the straps should be of unequal width, so that any chance of the plate being undercut at two opposite points is eliminated.

Joint 13. An increased strength is obtainable with this form of joint, provided that the workmanship is good and that fusion is effected at the inner corner of the fillet. The joint, like No. 7, is unsuitable for pressure vessels, and the efficiency is named as affording general information only. Owing to the uncertainty of the penetration at the inner corner of the fillet, it is considered that, where there is any doubt as to the quality of the workmanship, the joint when permitted should not be credited with an efficiency higher than 70 per cent. This joint shows the strength of weld metal in shear; efficiency $= \frac{\text{strength in shear}}{\text{strength in tension}}$

Joints 14, 15 and 16 give general information bearing on the additional strength obtainable with welds at the sides of straps. This form of weld does not, as is sometimes assumed, depend on the strength in shear of the weld metal at the surfaces of contact; nor is the strength dependent entirely on the area of cross-section at the throat of the fillet; or fracture in general follows one of the principal planes of stress, i.e., to a large extent it lies diagonally along the weld.

Joints 17 and 18 show the strength when straps are welded at the sides and ends.

Joint 19. The strength of the welds shown is referred to later.

Joint 20 is a modification of No. 4 and is referred to later.

Forms of Joint for High Strength.—A study of Table 1 makes it evident that, except possibly where the plate is thin, none of the joints 1 to 13, when used for the longitudinal seam of a pressure vessel, is an improvement on a plain butt weld. It is quite certain therefore that, with welds taken at only half their actual strength, makers must search for other designs if they desire to make use of a larger percentage of the plate strength.

The first alternative that suggests itself is the affixing of riveted straps to a butt-welded joint. This form of construction is particularly distasteful to the welder, who, apart from the question of cost, objects to the weakening of the plate and the liability of leakage being caused by the introduction of the rivet holes. In additon the weld is liable to be strained. With a seam made thus, and with the riveted joint designed

according to usual practice, the efficiency allowable is that of the drilled and weakened plate, and with butt straps of which the combined thickness is not less than that of the plate works out approximately as follows:

Description of riveting	*Fraction of plate strength*	*26 tons per sq. in. plate*
Single row of rivets; plates up to 1 in. thick..	0.66	17.3 tons per sq. in.
Double row of rivets; plates ½ to 1¼ in. thick (two rivets per pitch).....	0.75	19.5 tons per sq. in.
Double row of rivets; plates 9/16 to 1¼ in. thick (three rivets per pitch).....	0.80	20.8 tons per sq. in.

These figures compare with a rating of 12 tons per sq. in. for a plain butt weld, or, as will be seen later, more often only 10.8 tons per sq. in.

Though with a single strap this construction generally increases the efficiency to a value considerably over that of a plain riveted seam, it introduces bending stresses, which place a severe tax on the weld and add to the troubles resulting at any time from the use of a riveted single strap. Although the construction is not to be recommended from the point of view of its yielding a high-class joint, the figures given apply to non-fired vessels from the point of view of safety, for if the butt weld were to fail there would be a tendency for the whole of the load to be thrown on to the rivets, preventing sudden rupture, and before the load became excessive the magnitude of the leakage at the welded seam would necessitate the vessel being put out of use. With double straps the efficiency allowable is at best little more than that for a plain riveted construction. From the point of view of safety, therefore, the joint, when satisfactorily constructed, is only of slightly greater worth than a plain riveted joint, the principal value of the intermediate weld being to assis tightness. For this reason it cannot correctly be classed under th heading of welded joints.

Various forms of dovetailed and other strengthened joints have been suggested, but only one has come before the notice of the author's company that is suited for an appreciably higher rating than a butt weld. This is the ingenious device introduced by M. Hoehn of the Swiss Steam Users' Association, consisting of short transverse cover straps welded at intervals over the butt weld. The device is probably well known, and as a detailed description was given in the report referred to above, where the strength was analyzed at length, it will only be pointed out here that one of its main virtues from the safety point of view is that a joint can be made so strong that a greater load is required to tear the straps away from the plate than to break them. In addition the disadvantage, inherent to any longitudinal strap, of a rip taking place along the fillet weld and extending the length of the vessel is eliminated. Should a crack originate at a part of the butt weld between the straps it is arrested by the straps. This is a matter of the greatest importance, for it is just the ease with which a crack when once started can extend, which makes a welded joint more dangerous than a riveted joint.

As with other forms of joint, transverse cover straps should of course be well bedded and be jointed with ductile weld metal. The centers of transverse straps should be situated opposite one another, but the straps

should be of different length and width. Single straps introduce bending stresses and are permissible for longitudinal seams only when the plate is thin; their behavior in service cannot be gaged by a tensile test alone. If straps are placed alternately at the outside and the inside of the vessel, the stresses from bending are not quite so severe as with all the straps at the same side of the plate, but this design is only warranted with thin plates.

Up to the present this form of cover strap does not appear to have been developed in this country, but from an analysis of the strength there seems no reason why, with good workmanship and design, the joint should not be rated up to 90 per cent efficiency, and be used with safety for vessels larger in diameter than those considered by the present rules,

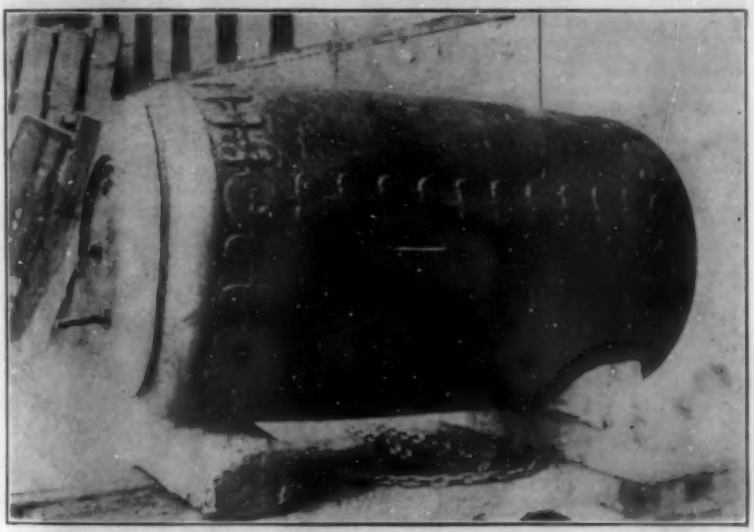


FIG. 1—AIR-VESSEL FITTED WITH DISCONTINUOUS COVER STRAPS

given in the Appendix. Fig. 1 shows the construction of an air-vessel fitted with these discontinuous transverse cover straps and the distribution of the straps at the longitudinal and circumferential seams. At the former there are straps at the inside as well as at the outside, but at the latter they are at the outside only. Special straps, which are welded all round and plug-welded at the center, are placed at the junctions of the longitudinal and the circumferential seams. The photograph was taken after a test, which is described immediately below, and it is to be noticed that while the shell is considerably distorted, especially at the belt, the longitudinal seam is undamaged. Fig. 2, which shows the same vessel turned round, indicates that when a strapped vessel is tested to destruction hydrostatically, fracture takes place through the solid plate, even away from the longitudinal seam.

Fig. 3 shows an air-vessel built for service, the working pressure being 427 lb. per sq. in. The internal diameter is 3 ft. and the length 15 ft. 6 in.

The plate thickness is 13/16 in. These three photographs have been selected from a collection kindly sent to the author by M. Hoehn, for the purpose of this paper.

The time may not yet be ripe, but there seems no reason to doubt that, when once confidence has been established in design and methods of construction, a device such as this will enable welding to be more generally approved and its use to be extended to vessels containing steam.

Weakness at the Junction of a Longitudinal and a Circumferential Seam.—It will perhaps make the system of rating more clear if, at this stage, attention is drawn to the fact that with a flanged dished end the bending movement at the flange gives rise not only to bending

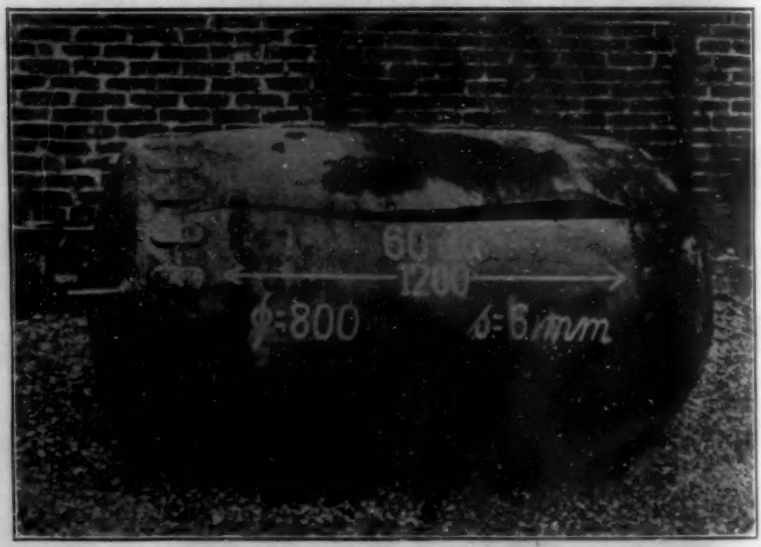


FIG. 2—VIEW OF AIR-VESSEL SHOWING FRACTURE

stresses at the circumferential seam of the flanged end but at the ends of the longitudinal seam. With the end well designed movement is slight only, but there is always a possibility of its taking place, owing to the tendency for an end under pressure to assume a spherical shape, the crown of an end concave to the pressure moving outward and the end of the shell inward. Again, with an end convex to the pressure, any bulging causes a radial thrust, with a resultant circular tension on the shell plate. There is therefore always a tendency for the end of a longitudinal seam to be more highly stressed than the remainder of its length, and the fact has on several occasions manifested itself by failure at the junction of a longitudinal with an end circular seam.

The situation was first met by M. Hoehn, who affixed an effectively designed circular or oval cover strap, welded all round, at the weak junction of a longitudinal with a circular seam. As the provision of some such strengthening device cannot increase the strength at other

parts of the longitudinal seam, the device does not allow the rating to be increased. In order, therefore, to encourage the adoption of this or an equivalent strengthening device and to keep the rating of a longitudinal seam below the value applicable when the end is rigid and

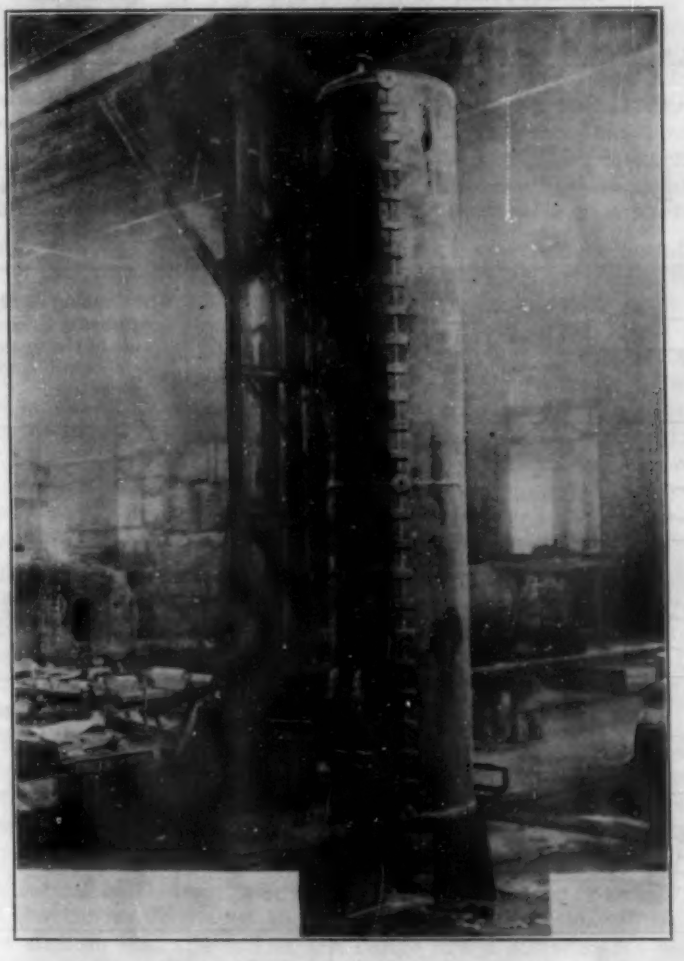


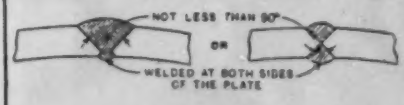
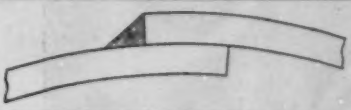
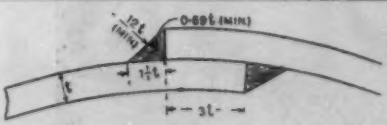
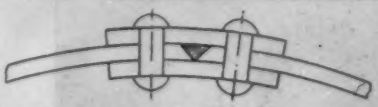
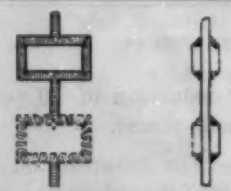
FIG. 3—AIR-VESSEL BUILT FOR SERVICE

no such secondary stresses are imposed, a deduction of 10 per cent is made from the ratings based on a simple tensile stress.

Rated Strengths of Longitudinal Joints.—For longitudinal joints of the principal types a comparison of the ratings, based on the considerations given, is shown by Table 2. The ratings do not apply to carbon-arc welding, and refer to vessels of which the diameter does not exceed 36

TABLE 2.—*Rated Strengths of Longitudinal Joints.*

Diameter not exceeding 36 inches.

Form of Joint.	Rated stress,* tons per sq. in.		Remarks.
	A	B	
	—	—	Can only be rated at a nominal value. Not permissible when the diameter exceeds 24 inches.
	12·0	10·8	The rating only applies if the inside of the vessel is accessible for inspection.
	—	—	Not permissible.
	6·6	6·0	Not permissible when the shell plate exceeds ¾-inch.
	17·2		For riveting up to standard boiler practice.
	19·5 20·8		Ditto.
	Up to 21·6		Depending on construction.

* The rated strength should be divided by the appropriate factor of safety.

inches, provided that they have been hammer-tested while being subjected to a hydrostatic pressure of double the working pressure.

Column B refers to a vessel fitted with a dished or other form of flexible end-plate that can impose a bending stress at the end of the shell. Column A refers to a vessel fitted with rigid end-plates, or with the ends of the joint specially reinforced to resist this stress.

Rated Strengths (Provisional) of Circumferential Seams.—It is always preferable for a dished end to be held independently of the joint, for instance, by the end of the shell being closed in over the flange, and a basic principle in any British rules hitherto published has been that any welded joint in tension shall be mechanically secured, independently of the weld. Likewise, with a seam joining two shell plates together, a joint supported by transverse cover straps is preferable to a plain joint.

Table 3 (pages 34-37) shows various types of circumferential joint. This drawing was omitted from the report, as the ratings given are still under consideration, but it was felt that the present paper would be deficient if no mention were made of the more usual forms of circumferential joint and no explanation given of the considerations that must influence the fixing of any rating. In the ratings shown, the encouragement of the best forms of construction has been deemed of more importance than a strict adherence to a system based on the test results. As before, the ratings apply only when the joints have been hammer-tested under hydrostatic pressure and when the diameter of the vessel does not exceed 36 inches. They do not apply to carbon-arc welding. The rated stresses refer to the axial stress in the shell plate.

The various constructions shown in the top line come under the heading of "corner" welds and are definitely not permissible. The ends are flexible, and the welds are situated at a point where the ends form an angle with the shell plates; the welds are therefore subjected to the full breathing motion of the ends. It is with welds of such inferior design that the majority of accidents occur.

The first three welds on the second line are also subjected to the full breathing action and are not permissible. Were the third weld rigid to the internal pressure, there would be no objection to its use; an end fixed thus should have a thickness not less than that of the blank flange that would be used, were the joint flanged.

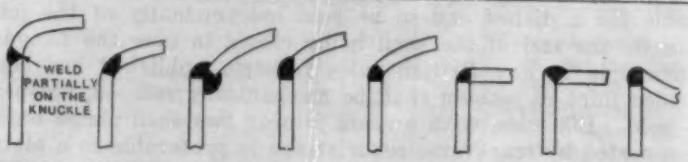
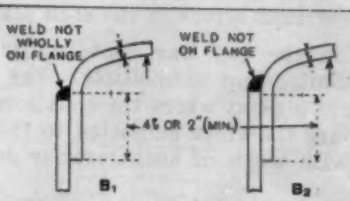
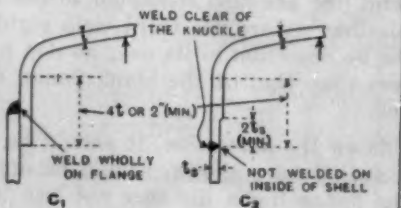
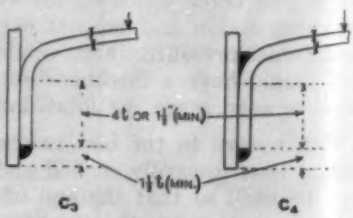
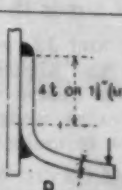
With regard to the last two welds on the same line, it should be explained that inwardly dished ends, such as are shown, should be driven into the shell so that the end of the flange lies a distance not less than one-and-a-half times the thickness within the shell.

Joints I, J1 and J2, where the ends are fixed independently of the weld, are given the highest possible rating, i.e., half the maximum possible rating of a welded or riveted longitudinal seam. It is to be observed that the extra wedge of weld metal in J2 could not in any event be relied upon to make the joint stronger than J1 (*see* remark against C4).

Joints C1 and C3 are, of course, simple lap joints subjected to an out-of-line pull, or with an efficiency of 50 per cent under tensile test. Here this primary bending action is reduced owing to the part being circular; it

TABLE 3.—*Ratings under*

Diameter not

Forms of End.


 


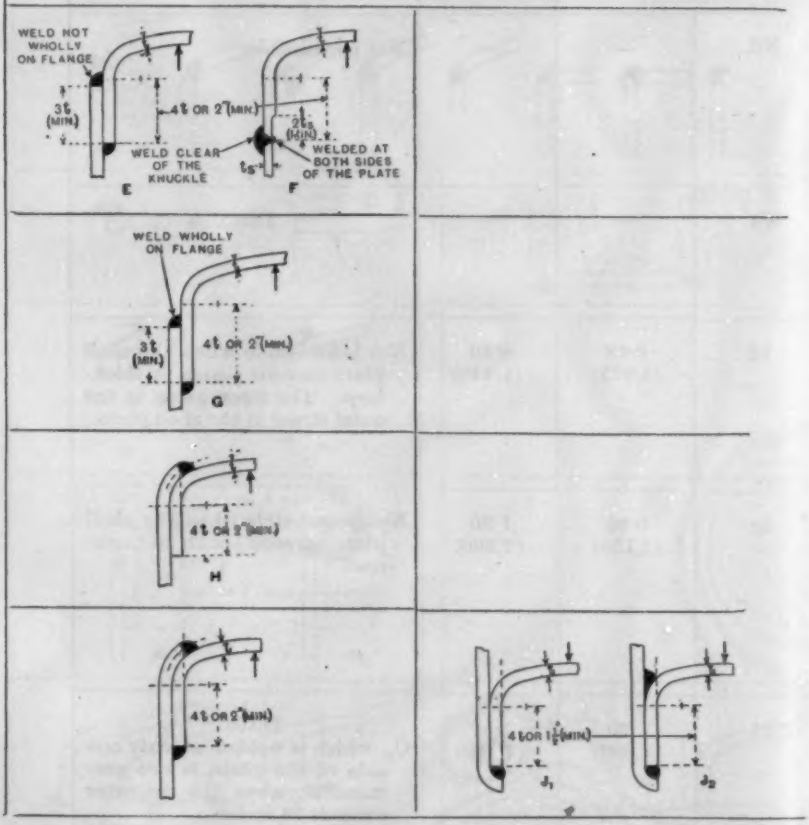
consideration for End Plates.

exceeding 36 inches.

Rated η, per cent.	Stress, tons per sq. in. (lb. per sq. in.)		Remarks.
	F.S.=5/1.	F.S.=4/1.	
Nil.	—	—	Not permissible.
Nil.	—	—	Ditto.
10	0·48 (1,075)	0·60 (1,340)	Not permissible when the shell plate exceeds ½-inch in thickness. The stress given is the axial stress in the shell plate.
20	0·96 (2,150)	1·20 (2,690)	Not permissible when the shell plate exceeds ½-inch in thickness.
25	1·20 (2,690)	1·50 (3,360)	Ditto. C_2, which is welded at only one side of the plate, is not permissible, when the diameter exceeds 24 inches.
30	1·44 (3,230)	1·80 (4,030)	Not permissible when the shell plate exceeds ½-inch in thickness.

TABLE 3.—

Forms of End.



is, however, not eliminated. On the other hand, the seam is subjected to an additional bending action, brought about by the movement of the end. The initial figure of 50 per cent is, therefore, retained as a basis, and the rated efficiency taken at half this value.

Joints B1 and B2 are offenders in that the weld is not clear of the knuckle as it should be, and the joint is subjected to a breathing action. In no instance should the length of the flange be less than four times its thickness, and a greater length is always desirable. A fillet weld should be entirely clear of the knuckle, and to discourage this vicious design, a deduction of 20 per cent is made from the last-named rating.

Joint G. On the same reasoning as is given for C1 and C3, the rating of this joint works out at 50 per cent, but on account of its being deemed

Concluded.

Rated η, per cent.	Stress, tons per sq. in. (lb. per sq. in.)		Remarks.
	F.S.=5/1.	F.S.=4/1.	
35	1·68 (3,760)	2·10 (4,700)	
40	1·92 (4,300)	2·40 (5,380)	
40	1·92 (4,300)	2·40 (5,380)	Provided that the end of the shell, as a minimum, is closed in by the amount shown by the drawing.
50	2·40 (5,380)	3·00 (6,720)	Ditto.

less safe than Joint I, the rating has had to be reduced to 40 per cent.

Joint E. The efficiency of this joint is the sum of those for B and C1, i.e., 45 per cent. As, however, the joint is inferior to G, the rating has been reduced to 35 per cent.

Joint F. The test efficiency is, of course, 100 per cent, but it cannot be taken higher than 45 per cent, owing to the bending of the end. Actually the figure has had to be reduced to 35 per cent in order to keep it below the value given for G.

Joint C2. This joint is distinctly to be discouraged, if permitted at all. The rating has been reduced appreciably below that named for the superior joint F.

Joint C4. The wedge of weld metal, which under certain circumstances might have the effect of assisting tightness, is placed at a most undesirable part, i.e., the knuckle, where cracks may readily be produced. In addition, the degree of penetration at the inner corner is problematical. It has, therefore, been found impossible to rate the joint at a higher figure than that given for C3.

Joint D. The wedge has the weaknesses named for C4. In recognition, however, of its yielding a measure of security in preventing an end flying off, the joint is rated at 5 per cent higher than C1.

Joint H. The efficiency has been reduced from the maximum to 40 per cent, as the joint, which occurs at the knuckle, is inferior to J1, and as a higher rating would discourage the superior I.

Joints A1 and A2. These are most unsatisfactory forms of weld; the weld is subjected to a severe bending stress that is liable to result in cracks. The mechanical method of securing the ends is most unsatisfactory, but a nominal rating has been given in view of leakage and a consequential stoppage of the plant being inevitable before an end can be blown out.

Tests to Destruction of Welded Vessels.—Four hydrostatic tests to destruction were specially made on small vessels for the purpose of the investigation, and a summary of the results, which were fully described in the report, is given below. Similar tests were arranged for and made on three other vessels, but unfortunately these turned out to give no information on welding. In addition to the data obtainable from the results given here, the data from a large number of previously made tests were used for the purpose of arriving at the ratings fixed for circumferential and longitudinal seams.

Test 1.—The internal diameter of the vessel was 16⅛ in. and the length 46 in., the shell plate thickness being ¼-in. One end was inwardly dished and was made of 11/32-in. plate. The longitudinal joint was butt-welded, and both ends were affixed by a welded lap joint with a single fillet of convex contour. The vessel was acetylene welded and was picked from stock. Working pressure was 150 lb. per sq. in. Failure took place at 950 lb. per sq. in. pressure, the inwardly dished end bulging outward. Pumping was continued until a crack was formed in the shell plate, close to the junction of the longitudinal and circumferential seams. The stress on the longitudinal joint at the time of the failure was 13.65 tons per sq. in., and the scantlings of the vessel were ample for the working pressure. The thicknesses were well proportioned, and the welding had been well carried out. The ratio of the actual bulging pressure to the bulging pressure calculated by Bach's formula for a riveted seam was 75 per cent.

Test 2.—The internal diameter of the vessel was 16 in. and the length 16 in., the shell plate thickness being 0.107 in. One end was inwardly dished and was made of 0.141-in. plate. The longitudinal joint was lap-jointed and single-riveted, and both ends were affixed by a welded lap joint with a single fillet, the ends of the shell being closed in over the flanges of the end plates. The vessel was metallic-arc welded, and was picked from stock. Working pressure was 150 lb. per sq. in. Failure took place at 410 lb. per sq. in.; the inwardly dished end bulged outward and the pressure dropped. The stress on the longitudinal joint was 13.7

tons per sq. in. The vessel was too weak for its designed working pressure. The ratio of the actual bulging pressure to the bulging pressure calculated by Bach's formula for a riveted seam was 80.1 per cent.

Test 3.—The internal diameter of the vessel was 12 in. and the length 22 in., both the shell and the ends being ¼-in. thick. The longitudinal joint was butt-welded and reinforced at both surfaces of the plate. Both ends were outwardly dished; one was butt-welded to the shell and reinforced at both surfaces; the other driven into the shell and affixed by a welded lap joint with a single fillet of straight contour, the weld being situated at the end of the flange, close to the knuckle. The vessel was metallic-arc welded, the electrodes being wound with asbestos, and was specially constructed for the inquiry. At 1500 lb. per sq. in. the shell developed a Spence hump, and at 2250 lb. per sq. in. the end that had been lap-welded was blown out of the shell and projected for a distance of several feet. At this time the stress on the longitudinal seam calculated for single-dimension stress, was 24 tons per sq. in., or the full strength of the weld metal. The behavior of the lap weld, which failed, was exceedingly satisfactory, in consideration of the following facts: (1) the end was initially ill-shaped and had subsequently been considerably distorted; (2) the weld was close to the knuckle, where it was subjected to bending stresses from this distortion and the bulging of the end under pressure; (3) the weld was stressed by the bulging of the shell plate.

Test 4.—The same vessel was used. A new end, of the same thickness as before, was affixed by a butt joint. The welding was carried out from the outside only of the plate, the inside being inaccessible to the operator. The outside of the weld was ground off level with the plate. At 2500 lb. per sq. in. the longitudinal joint failed with a loud report, and a tear 11¼ in. long was caused at the bulge previously referred to. The tear extended to the circumferential weld of the new end plate, and in one direction traveled 4¾ in. round the circumferential joint, while at the other it turned off into the metal of the end plate. The stress on the reinforced longitudinal seam, calculated for single-dimension stress and based on the original diameter, was 26.8 tons per sq. in., or the apparent efficiency of the reinforced joint was 111.8 per cent. Naturally the single-dimension stress at the circumferential joints was only half this value. The new joint, therefore, had only to carry a comparatively low steady stress, which it was easily able to withstand. Although, therefore, the weld metal had, at intervals only, penetrated the full thickness of the plate, the stress on the new joint was comparatively low; the stress being steady (not fluctuating as it would have been in service), the joint was not overtaxed by the test. As the limit of the plate strength was reached, the original intention, which was to strengthen the longitudinal joint and extend the test to improved forms of circumferential joint, had to be abandoned.

Inwardly dished ends.—The design of inwardly dished ends is a matter of importance with pressure vessels, owing to the stress imposed on the weld in the event of its inverting or becoming partially inverted. It is common, on a hydrostatic test to destruction, for a weld on an inwardly dished end to be the first part to fail, owing to the end bulging. From

this it does not necessarly follow that the end is unduly weak, but merely that it is the weakest part. On the other hand, in many instances the bulging pressure has been far too low, and failure would not have occurred had the end been convex. This does not necessarily point to an inwardly dished end being undesirable, but it does show that its design is more often than not incorrect. In addition to insufficiency of scantling, malformation can readily cause incipient collapse.

An analysis was given in the report showing that with a welded vessel designed for a uniform factor of safety, but with the weld rated at only half its possible strength, it is only to be expected that the first failure on hydraulic test will be caused through the bulging of an inwardly dished end. If the vessel were riveted, and all parts designed to the same factor of safety as before, one of the seams, either longitudinal or circumferential, would fail at the bulging pressure.

With vessels having inwardly dished ends, designed so that the bulging pressure is below the pressure for failure elsewhere, the preference lies with a riveted rather than with a welded end, owing to the greater danger of cracks being formed in the circumferential joint in the event of an end bulging. This form of end tends to act as a cushion in the event of sudden rises in pressure, but, in so acting, it will probably set up dangerous bending stresses in the joint.

A point that does not appear to be generally appreciated is that the usual form of fusion-welded inwardly dished end inverts at a lower pressure than does a similar riveted end. This is on account of the flange being less rigidly held. It is necessary, therefore, that provision should be made for this in the design. When the end is fusion welded, an incidental disadvantage of its being inwardly dished is that it cannot be butt-welded to the shell and it does not adapt itself to a double-fillet lap joint. It cannot, therefore, be given as high a margin of security as is possible with an outwardly dished end, unless the ends of the shell are closed in. An inwardly dished end calls for careful design, and rules 12 and 13 giving the construction of the most common form are given in the Appendix.

TABLE 4.—*Ratio of End-plate Thickness to Shell Thickness for an Outwardly Dished End to Bulge at the Same Time as the Longitudinal Seam Fails.*

η = Efficiency of longitudinal seam

	Pressure for failure, lb. per sq. in.		
Construction	500	1,000	2,000
End riveted; longitudinal seam riveted	2.89η	2.47η	2.22η
End riveted; longitudinal seam riveted when η = 0.60	1.73	1.48	1.33
End fusion-welded; longitudinal seam riveted	3.42η	2.97η	2.69η
End fusion-welded; longitudinal seam riveted when η = 0.60	2.05	1.78	1.61
End fusion-welded; longitudinal seam fusion-welded	2.93η	2.55η	2.31η
End fusion-welded; longitudinal seam fusion-welded when the rated η = 0.45	1.32	1.15	1.04

The thickness of an inwardly dished end for a welded vessel does not by any means bear any relationship to the usual thickness used for a riveted vessel. The determination of each is a different problem. Table 4 shows the relationship between the thickness of the end plate and the shell plate for vessels of different classes of construction, designed as recommended with the plate of boiler quality steel and the bulging pressure equal to the pressure required for failure of the longitudinal seam, a welded longitudinal seam being assumed to be butt-welded without cover straps and its strength against failure taken at the rated strength.

With end plates of the thickness indicated, the stress, calculated from the sphere formula by use of a factor of safety not less than 4, is in no instance excessive. It is to be noticed that, with an all-welded vessel, the thickness of the end plate relatively to that of the shell plate is, especially with low pressures, considerably less than its value when the longitudinal seam is riveted, and this in spite of inversion taking place at a lower pressure. This is, of course, due to the lowness of the rating with welded joints involving a thicker shell plate.

Fillet Welds.—No general study appears to have been made of the strength of the various forms of fillets in use. A method of calculating the stress that is commonly adopted is to divide the axial load by the cross-sectional area at the throat of the fillet and to treat the quotient as the actual stress carried at the weakest section. The method entirely ignores the fact that the section under consideration has to carry a shear as well as a tensile load, and that the true stress is a combination of these components.

Now, if a fillet weld is treated as if there is no penetration, and the weld metal makes an angle at its inner corner, then, according to elastic theories, enormous concentrations of stress will occur at the inner corner, and failure under light loading can only be prevented by plastic flow taking place in a ductile material. The severity of the loading is evident from Fig. 4. A typical joint where the conditions are favorable, the bedding being good and the pull equalized, is shown at the left. At the right the weld metal, plate, and strap are shown solid, and the inactive metal is separated by an imaginary slot. Drawings of this type have been found invaluable for studying the stresses in various forms of weld.

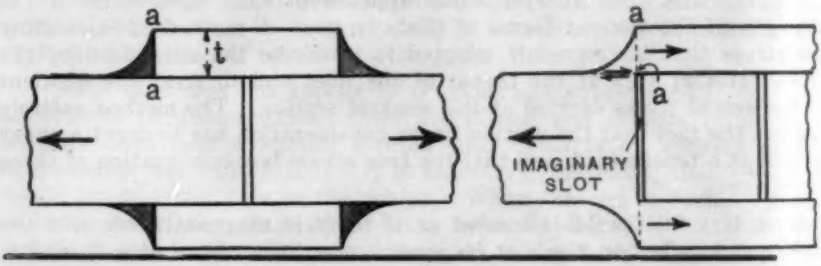
As the conditions are modified by the penetration that occurs with a well-made weld, it was felt that a study from the elastic standpoint would not serve any useful purpose. Though no exact method of treatment suggested itself, it was considered that the existing method already described might well be improved. An analysis was therefore made of the stress, on the assumption that the loading was uniform along the radial section of the fillet under consideration. It was felt that there was some justification for this course on account of the fact that the stress would tend to become uniform if the weld were loaded axially to the breaking point, and that it was more convenient to rate the weld on its breaking load than on its elastic limit. As the depth of penetration at the inner corner of a fillet is always an uncertain factor, no credit was given for any extra metal there. The analysis was given in full for

several forms of fillet. This showed that the resultant stress from the shear and tension could be taken, with sufficient accuracy, as being 15 per cent higher than the axial load divided by the area of the radial cross-section at the throat of the fillet. Actually, if the remaining cross-sections are considered, the percentage increase reaches a maximum value of 15.45 at a section lying at 54¾ deg. from the vertical.

The efficiencies of the joints considered were based on the calculated stresses, and as they show the relationship between the strength of the fillets and that of the plates, on the assumption that both are of the same material, it is of no consequence of what material they are made as long as both are similar. It is therefore logical for the efficiencies obtained to be taken for the purpose of comparing the strength of a fillet weld with that of a butt weld in the plate.

The calculated efficiencies are given by Table 5 (pages 43-44). The original intention was to formulate an easy method of estimating strengths, and it was not anticipated that the latter would altogether

FIG. 4.



agree with those obtained from tensile tests. However, in view of the enormous difficulty in obtaining a weld of the exact contour required and of the variation in penetration, it was found that the agreement was sufficiently close for estimations of strength to be based on the calculated figures.

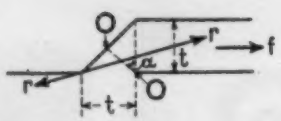
The tests showed that the efficiency of a good weld with a straight or a full-concave contour could be reckoned to exceed 60 per cent; this efficiency, when the surfaces of contact in tension and shear are equal, corresponds with a concave contour with a radius of $12t$, which gives a throat thickness of $0.69t$, and a nearly straight profile, the deviation from a straight line being only $0.02t$. For these reasons a standard efficiency of 60 per cent was adopted for throat thicknesses not less than, say, $0.7t$.

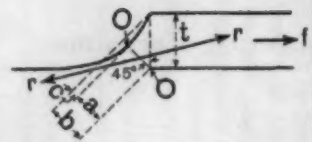
As the strength of sound weld metal in shear is only 80 per cent of the strength in tension, the efficiency of the various joints shown by the table can never exceed this figure, unless the breadth of the surface of contact in shear is made greater than the plate thickness. With a fillet weld sufficiently full and with bending stresses absent, 100 per cent efficiency is theoretically obtainable when the breadth of the shear surface is one and a quarter times the plate thickness.

TABLE 5.—*Efficiencies of Fillet Welds.*

Surfaces of contact free from bending.

—	Radius = t		Radius = $2t$	At shortest section, i.e. $\beta = 90°$, or $\cot a = n$				
Resultant Stress, r	$\frac{f}{2}[\cos a + \sqrt{4 - 3\cos^2 a}]$. Maximum value occurs when $a = 54\frac{1}{4}°$		—	$\frac{f}{2}\left[1 + \frac{\sqrt{4+n^2}}{n}\right]$				
	$a = 45°$	$a = 54\frac{1}{4}°$	$a = 45°$	$n = 2$	$n = 1\frac{1}{2}$	$n = 1$	$n = \frac{1}{2}$
Resultant Stress, r	$1{\cdot}144f$	$1{\cdot}155f$ (max.)	$1{\cdot}368f$	$1{\cdot}207f$	$1{\cdot}333f$	$1{\cdot}618f$	$1{\cdot}924f$
Joint strength expressed as a percentage of the strap strength (on the assumption that the weld metal has a strength equal to the original metal).	87·4	86·6	73·1	82·8	75·0	61·8	52·0
Thickness of weld at section OO.	t	t	$0{\cdot}836t$	$0{\cdot}894t$	$0{\cdot}832t$	$0{\cdot}707t$	$0{\cdot}600t$



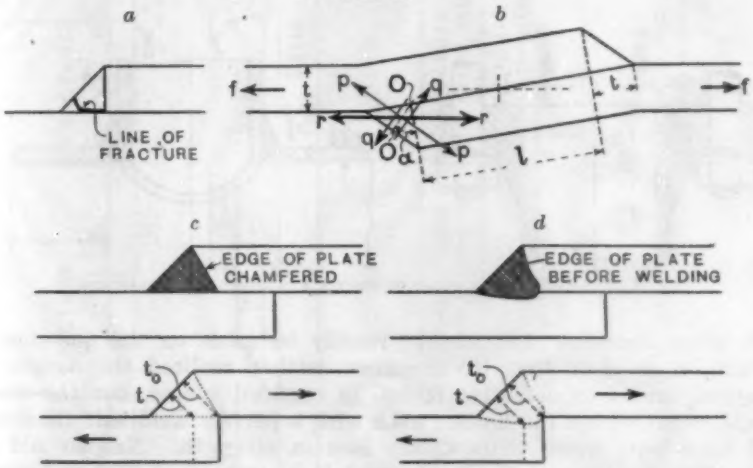


—	—		$\alpha = 45°$, Radius $= nt$, but $n \not< 1$							—
Resultant Stress, r	$f\frac{\cos(\alpha-45°)}{\sqrt{2}}\left[\cos\alpha+\sqrt{\frac{5-3\cos 2\alpha}{2}}\right]$ Maximum value occurs when $\alpha = 48\frac{1}{2}°$		$\frac{1\cdot618}{1-1\cdot4142n+\sqrt{2n^2-1}}f$							—
	$\alpha = 45°$	$\alpha = 48\frac{1}{2}°$	$n=\infty$	$n=20$	$n=12$	$n=10$	$n=8$	$n=3$	$n=2$	$n=1$	$\alpha = 45°$
Resultant Stress, r	$1\cdot618f$	$1\cdot624f$ (max.)	$1\cdot62f$	$1\cdot65f$	$1\cdot67f$	$1\cdot68f$	$1\cdot69f$	$1\cdot84f$	$1\cdot97f$	$2\cdot77f$	$1\cdot618\frac{b}{a}f$, or $1\cdot144\frac{t}{a}f$, or $\frac{1\cdot618}{1-\sqrt{2}\frac{c}{t}}f$
Joint strength expressed as a percentage of the strap strength (on the assumption that the weld metal has a strength equal to the original metal).	61·8	61·6	61·8	60·6	60·0	59·5	59·1	54·3	50·8	36·1	$\frac{100\left(1-\sqrt{2}\frac{c}{t}\right)}{1\cdot618}$
Thickness of weld at section OO.	$0\cdot707t$	$0\cdot708t$	$\cdot707t$	$\cdot694t$	$\cdot686t$	$\cdot682t$	$\cdot676t$	$\cdot623t$	$\cdot578t$	$\cdot414t$	a, or $(0\cdot707t - c)$

In certain instances it is desirable that fillets should not be too rigid. To meet this a convenient rating, based on the throat thickness being kept above $0.7t$, is 50 per cent. This corresponds with a concave weld of radius $2t$. Where fusion is defective, fracture naturally will not occur near the throat. A typical manner in which it takes place is shown by Fig. 5*a*, item 1.

Set Lap Joint.—Analysis of fillets with straight profiles lying at 45 deg. to the surfaces of the plate showed that at the section OO, where $\alpha = 45$ deg. (see Fig. 5*b*), the theoretical efficiency of a single fillet is 60 per cent when l equals $4t$, and 59.7 per cent when l equals $3t$. At the section of greatest stress the theoretical efficiency, where l equals either $3t$ or $4t$,

FIG. 5.



is approximately 58 per cent, and the overall efficiency of the joint just over 116 per cent. Calculation, therefore, gives no promise that the joint will give an efficiency higher than that actually obtainable with straight lap-welded joints with two fillets. The limited number of tests made tended to confirm this conclusion, and, in fact, showed that the calculated efficiency might even be too high owing to spring at the bends.

Modified Form of Fillet.—Obviously, with the plate chamfered in the manner shown by Fig. 5*c*, or with deep penetration at the inner corner of a fillet (see Fig. 5*d*), the efficiency of the fillet can be raised. With the former type of weld, the surface of contact in shear is increased and the true throat thickness becomes t_o, against an apparent thickness of t. It is essential, for a good weld to be obtained, that the inner corner of the fillet should be well rounded. With the latter type of weld the result is very similar, but the weld is often defective at the inner corner.

General Remarks on Pipe Fittings.—At the very start of the investigation it was realized that, as fittings had been welded to steam-pipes for a considerable number of years and as similar fittings were very often

required for pressure vessels, the undertaking would not be complete unless a study were made of the strength of the joints used on fittings.

The consideration given here applies to fittings affixed by fusion welding only, and does not apply where there is a mechanical interlock or the joint is partially or wholly made by forge welding.

Evidence of the fact that it is not only unskilled makers who are in need of guiding principles governing design but also certain compilers of specifications, is provided by Fig. 6, which shows an inferior method by which it was specified that flanges and branches should be welded to steam-pipes for 350 lb. per sq. in. working pressure, the specification calling for the carbon-arc to be used, and therefore debarring makers, should they have so desired, from using a superior process of welding.

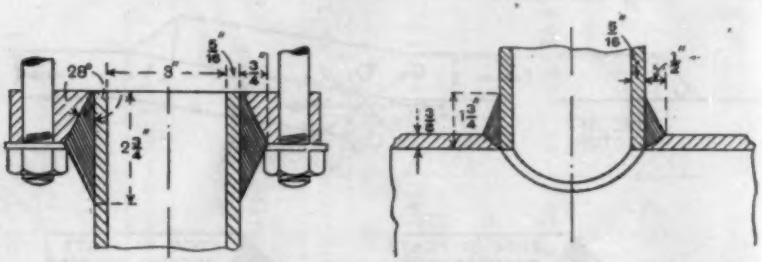


FIG. 6—INFERIOR METHOD OF WELDING FLANGES AND BRANCHES

Apart from comment that might readily be made on the question of strength, it is clear that the designer neither realized the danger of entrapped oxides or defective fusion in confined spaces, nor the waste of weld metal within the flange; even with a perfect weld half the metal could have been saved without any loss in strength. Neither did he realize that ductility of the weld metal is all-important with a branch, that the fierce flame of the carbon-arc burns away the sharp edges of the original plate, and that he was not making provision for accommodating the bolts within the flange. The designer would have been better advised if he had left the details in the hands of reputable pipe makers.

Beyond the fact ascertainable by hydrostatic test, that sound welds of certain designs will withstand a greater pressure than the tube, information bearing on the exact strength of joints is very scanty. As a result of the fact that each maker has independently developed his own designs in the absence of any agreed strength, there is a wide divergence of practice, and one maker may provide a strength on a branch tube of only a quarter or a fifth of that given by a good design. Knowledge that the weld is stronger than the plate is insufficient. If the only information on the strength was that obtained by hydrostatic test, no more credit could be given to makers who produced a weld of 200 per cent efficiency than to those who gave only 101 per cent.

Though the recording of any general rules for fittings was withheld from the report, it was shown how the strength to resist axial pull of the principal welds could readily be estimated. The criterion for strength

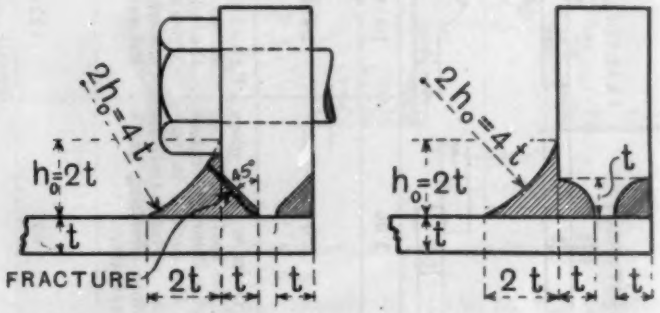
FIG. 7.—*Various Forms of Weld on a Flange.*

Width of useful section of metal	$0{\cdot}707h$	$1{\cdot}0h$	$1{\cdot}414h$	$0{\cdot}707(m+1)h$	
Weld metal Economy ratio $=\frac{\text{Thickness of weld metal at fracture} \times h}{\text{Cross-sectional area of weld metal}}$	$1{\cdot}414$	$2{\cdot}0$	$1{\cdot}414$	$\frac{1{\cdot}414(m+1)}{(m^2+1)}$	
Note	—	The fracture takes place at the surface of contact in shear rather than at the surface in tension, owing to the former breaking at a lower stress.	Fracture as shown, unless the plate is of weaker material than the weld.	The tube is actually the weakest section when the weld is of good quality; the fracture shown indicates the weakest part of the weld.	
Calculated Efficiency, per cent	(Fillet concave; radius $< 2h$) $50{\cdot}8$	80	$123{\cdot}6$	$(m=1)$ $123{\cdot}6$ $(m=1\frac{1}{2})$ $154{\cdot}5$ $(m=2)$ $185{\cdot}4$	
Do. corrected, per cent	(Fillet concave; radius $< 2h$) 50	70	(Fillet concave; radius $< 2h_0$) 100	$(m=1)$ 100 $(m=1\frac{1}{2})$ 125 $(m=2)$ 150	

rests on whether it is requisite for the joint to possess an axial strength equal to that of the plate, or to carry, without failure, the same internal pressure that the longitudinal seam or the shell plate can withstand along its length. The most logical method of dealing with flanges and branches was considered to be to determine the strength in terms of the tube thickness.

Flanges.—If a flange is considered to be stiff and the bending stress from the bolts is neglected, the strength is easily computed from the data already given, and allowance for stress due to flexure should be made when the scantlings are fixed. Fig. 7 shows various forms of weld on a flange, and from these basic forms strength of any of the usual types of weld on a flange can be determined. The positions of fracture

FIG. 8.—*Flange Welds.*



have been verified by means of models where the wall of the tube has been strengthened, and the positions indicated on the sketches are obviously intended to show the weakest part of the weld, not of the tube. In each instance fracture takes place at a different position, as is made evident from the lower key diagrams. The economy ratio given is not intended for practical application but to indicate the direction in which, according to theory, economy of weld metal is to be sought.

The efficiencies compare the strength of the weld with the axial strength of the welded tube. Owing to the uncertainty, previously referred to, of the interior of the weld being sound, the second weld is credited with only 70 per cent efficiency. The method of arriving at the strengths of the third and fourth welds was described in the report and, as with the second weld, a deduction has been made in the efficiencies credited; owing to the thickness of the highest stressed section being inappreciably altered with changes in contours of the fillet, the lower figure is applicable when the fillet is concave and the radius is not less than $2h_o$, or (where $m = h_o/t$) is not less than $2m$ times the thickness of the tube.

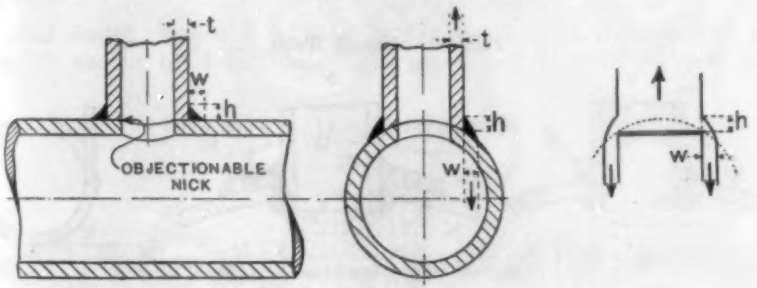
With flanges, an easy radius at the fillet is to be desired as, in consideration of the heavy bending stresses set up when the bolts are tightened, undue stiffness and sudden changes of section may lead to trouble.

From the foregoing it follows that the efficiency of the welds shown by Fig. 8 is 220 per cent. This reckoned on a weld strength of 24 tons

per sq. in., the standard adopted with a metallic arc weld, gives 52.8 tons per sq. in., or the strength to resist an axial force is just over double that possessed by the metal of a tube with a strength of 26 tons per sq. in. The left-hand sketch shows that, on the rare occasions where, with a British standard flange, it is required for weld metal to be cut away for the head of a bolt, the cutting away can be effected without a reduction in strength. The right-hand sketch shows a more suitable preparation where the carbon-arc process is to be adopted. With a carbon-arc weld taken at 20 tons per sq. in., the axial strength of the form of joint shown is 44 tons per sq. in., or only 1.7 times the metal strength.

With the stress assumed to be set up by the internal pressure alone, the maximum stress in a circumferential seam could not, of course, exceed

FIG. 9.—*Elementary Form of Branch Weld.*



13 tons per sq. in. The designs indicated, therefore, give a high margin for subsidiary stresses, and are of equal strength to good designs that have already been evolved by manufacturers and that are already in service.

Branches.—An elementary form of weld not recommended for branches is shown by Fig. 9. The diagram at the right-hand side gives, as before, an indication of the stresses at the weld set up by the direct pull; the inward flexure is largely resisted by the metal surrounding the hole cut in the wall of the main pipe. The inappreciable strengthening of the weld, owing to each element when viewed in plan being the sector of an annulus and not a rectangle, is neglected. Likewise the ring of weld metal is treated as being circular and not saddle-shaped, the latter being the actual form of a branch affixed to a rounded vessel or pipe.

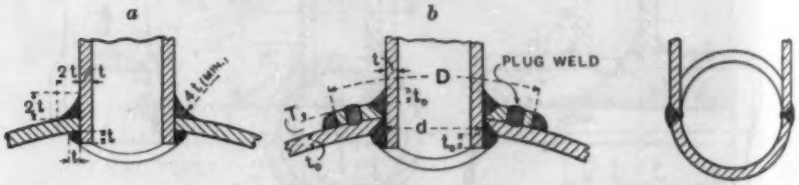
The strength of a weld made, as shown, has already been discussed, and it will be gathered that, with h and w each equal to t, the basis efficiency in relation to the strength of the branch tube is 50.8 per cent, or, say, 50 per cent, provided that the radius at the fillet is not less than $2t$, and that the tube is fixed to a rigid wall. With the dimensions w and t doubled, and the radius not less than $4t$, the efficiency is of course doubled. With a dummy, representing a 9-in. branch with rigid walls, welded to a rigid plate by the metallic arc process and tested hydro-

statically, the weld efficiency computed for a concave profile was 49.8 per cent, which is in very fair agreement with the efficiency just given.

When the branch is welded in the usual manner, not only is there a small bending stress set up by the axial pull but, more important, the efficiency is reduced, owing to the wall of the main pipe or vessel being flexible. With a standard branch of 4½-in. bore, welded to a flexible flat header by the same method as before, and tested hydrostatically, cracks were set up in the weld owing to distortion of the header. The computed efficiency for a concave profile, reckoned on the collapse of the header, was 38.5 per ent, the efficiency having only 0.774 times its previously named value.

It is realized that a considerable amount of experimental work is required to determine the variation of strength of the different designs of branches that occurs with alteration in the bore of the branch in relation to that of the main pipe. It is considered, however, that the

FIG. 10.—*Branch Welds.*



D should be not less than $\left(1+\frac{t_0}{T}\right)d$.

suitable working stress depends more on the stress at the time of the first permanent set than on the bursting pressure. In the meantime a ready basis for determining strengths suggests itself.

It was considered that the minimum requirement for the welded joint on a branch tube is that the weld should be capable of withstanding the same internal pressure as a longitudinal section through the solid wall of the tube. As a first consideration, therefore, the axial strength of the joint should be not less than half the strength of the parent metal. With the joint rated at half the actual strength and the weld metal of equal strength to the metal of the tube, this requirement calls for a fillet of the contour specified to have a height not less double the thickness of the branch tube. With the useful strength assumed to be lowered by flexure to 0.8 times the calculated value, the minimum height for the fillet should be 2½ times the thickness, this as before assuming that the weld metal is as strong as the metal of the tube, i. e., 26 tons per sq. in. On this basis, therefore, the height with weld metal of a strength of 24 tons per sq. in. should be not less than 2¾ times the tube thickness, as long as the radius is not less than twice the height. For welded branches for pressure work, the carbon-arc process was deemed unsuitable.

Naturally the main tube is weakened by the hole cut in the wall to receive a branch. It was, however, shown in the report that the required amount of reinforcement would be given and the weld would be suf-

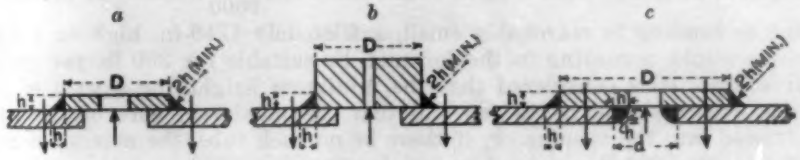
ficiently strong to transmit this stress, if a 4-in. length of the metal of the branch tube was assumed to be effective in giving compensation and the bore of the branch did not exceed 8 in.

In the design so far studied (*a*) the metal is unfavorably situated to give compensations; (*b*) the fixing lacks rigidity for withstanding stresses set up by expansion or by bending or twisting stresses communicated from the branch piping, and (*c*) the objectionable nick tends unnecessarily to set up high local stress in the weld metal.

In no instance should a gap be permitted between the tube and the part on to which it is mounted, whether the former is laid on or let into the latter. If a branch is kept short, considerable improvement is, as a first step, readily obtainable by the two metals being fused together by an oxy-acetylene torch, applied from the top of the branch. The carbon arc is also sometimes used, being applied from the end of the main tube.

A good design, where it is possible for metal to be deposited at the inside, is shown by Fig. 10*a*. This gives better reinforcement and

FIG. 11.—*Welded Fittings.*



rigidity. Here, a total height of 3*t* is obtained by a weld 2*t* high at the outer side, and a weld 1*t* high at the inner side of the vessel. The design lends itself to the attainment of high axial strength, without a fillet becoming unduly large. With some such design as is shown by Fig. 10*b*, better compensation for the hole is given than with a riveted construction. The welds, when arranged as shown, have a combined strength equivalent to a single fillet weld of height 4*t* (see Fig. 10*c*).

If the diameter of the branch is increased until the bore equals that of the tube to which it is fixed, there is no difficulty in arranging for the weld to have an axial strength equal to that of the tube, the strength of the latter being assumed as before to be lowered to 24 tons per sq. in. This is effected in the manner shown by Fig. 10*c*; the joint is in the form of a butt weld with the main pipe viewed in cross-section, and is gradually tapered to a fillet weld of height 2*h* in longitudinal section. It is, however, difficult to see how further strength can be obtained in a satisfactory manner unless cover straps are fitted. With any branch, care should be taken that the joint is not assessed at a higher figure than that for the average strength round the whole ring of weld metal.

The fact that branches of so much smaller scantlings than those indicated stand up in service is due to the board of trade formula for the thickness of a lap-welded steel tube being usually based on a factor of

safety of 13, plus a wastage allowance, the equivalent factor for a solid-drawn tube being 10. However, with this or any other rule in force, in any rating that may ultimately be fixed it would appear to be illogical to allow the attachment of the fitting to be weaker than the wall of the tube.

Bosses, Reinforcing Plates, etc.—(*a*) Fittings of the type illustrated by Fig. 11*a* and *b*, should, only when the size is small, be welded in the manner shown. As is to be seen from the figures that follow, there is no difficulty in obtaining a weld of enormous axial strength provided that flexure is reduced to a minimum. As there is no internal joint the internal pressure (p lb. sq. in.) acts on an area with an outside diameter D (inch), and the force tending to tear the fitting away is $\frac{\pi D^2 p}{8960}$ tons. The shear stress at the junction of the weld metal and the fitting is therefore $\frac{pD}{8960h}$ tons per sq. in. But with weld metal of 24 tons per sq. in. strength, a factor of safety of 4, the fillet with a radius of not less than $2h$, and the efficiency rated at 20 per cent (i.e., half 40 per cent, or 0.8 times 50 per cent, the figure adopted with branches), the allowable shear stress is 0.96, or say 1.0 tons per sq. in. It follows, therefore, that the required height of fillet h is, in round numbers, $\frac{pD}{9000}$ inches. If the stress due to bending is reasonably small, a fillet only 1/10-in. high on a 3-in. circle would, according to the formula, be suitable for 300 lb. per sq. in. pressure. It is considered that the minimum height for a weld of the type shown should be ¼ in., and that the maximum bore of the tube screwed into the opening or, if there be no such tube, the maximum bore of the opening should be 2 in.

(*b*) A better plan is to weld internally, as well as externally, in the manner shown by Fig. 11*c*. If for convenience the two welds are assumed to be of equal height, the height when worked out as before is $\frac{pd^2}{9000\ (D + d)}$ or, simplified $\frac{pd}{18{,}000}$ inches, the simplification increasing the margin of safety. It is considered here that the height of the fillet should be not less than 3/16 in.

Provisional Rules.—The rules, which have tentatively been drawn up, are given in the Appendix. In a first draft it would, of course, be unwise to attempt to cover every possible requirement, but it has been attempted to make the rules sufficiently comprehensive to cover the most common forms of construction. The rules, as drafted only cover vessels up to 36 in. in diameter. The aim has been to indicate the designs considered most suitable, but to avoid dictatorial regulations handicapping makers in the development of any other form of design that may prove equally suitable.

In regard to Rule 7, particular emphasis is laid on the necessity for all joints to be well hammered at the time of the initial hydrostatic test. As it is not unknown for a joint to fail or for cracks to open out while the pressure is falling, a precaution prescribed is that pressure shall be reapplied.

TABLE 6.—*Repeated Impact Tests.*

Process.	Description of welding rod or filling material.	Treatment.	Stress reversals.	Average
Unwelded mild-steel plate	—	As received	7,000/8,000	(7,500)
Oxy-acetylene	Swedish charcoal-iron rod	As received	1,354/4,184	(2,769)
		Normalized 910° C.	1,296/5,181	(3,238)
Electric (carbon arc)	Mild-steel filling	As received	283/800	(542)
		Nor. 910° C.	1,008/1,406	(1,207)
,,	Swedish charcoal-iron filling	As received	622/810	(716)
		Nor. 910° C.	408/865	(636)
Electric (metallic arc)	Bare wire; mild-steel rod	As received	751/800	(775)
		Nor. 910° C.	512/712	(612)
,,	Bare wire; Swedish charcoal-iron rod	As received	791/1,436	(1,113)
,,	Rod with light wash	,,	542/737	(640)
,,	,,	,,	864/956	(910)
,,	,,	,,	913/1,388	(1,150)
,,	Lightly flux-coated rod (weld made by makers)	,,	1,330/1,808	(1,569)
,,	Thickly slag-coated rod	,,	682/878	(780)
,,	Wound rod	,,	2,471/5,988	(4,230)
,,	Wound rod (same rod as last specimen, but different welder) (weld made by the electrode makers)	As received	904/1,287/2,361/2,622	(1,793)
		Nor. 910° C.	3,161/3,894	(3,528)
,,	Wound rod of special composition (weld made by the electrode makers)	As received	2,580/4,974/7,146/7,197	(5,474)
		Nor. 910° C.	4,206/5,050	(4,628)
,,	Slag-coated rod of special composition	As received	5,400/7,621	(6,510)
,,	Special wound rod (weld made by the electrode makers)	,,	2,900/4,971	(3,935)
,,	Special wound rod (weld made by the electrode makers)	,,	8,300/8,647	(8,473)

It is folly for a test pressure to be fixed irrespective of design. A high test pressure may lead to considerable distortion of ends and to serious strain at joints. Should a high test pressure be deemed desirable for a particular vessel, there is no difficulty in its being designed accordingly.

Future Extensions of Welding.—A certain amount of experimental work has been carried out on the strength of welds at high temperatures. Experimental work is still lacking on the limiting creep stress of weld metal and the fatigue range at high temperatures. For confidence to be placed in welds working under fluctuating stresses at high temperatures, such experimental work is much needed, not only for one or two particular welds, but for a range of welds of different quality.

Part II.—Physical Properties of Weld Metal

The subject-matter contained in this portion of the paper is only dealt with briefly, as full details were given in the report on the investigation.

Analysis.—Wherever it was considered that useful information would be obtained, analyses were made of electrodes and the deposited weld metal; the results of these were found to be of great value in yielding data for conclusions. As samples were furnished by courtesy of manufacturers, results have been withheld from publication.

Tensile Strength of Weld Metal.—A large number of tensile tests was made, apart from the tests on which joint efficiencies were determined. These were carried out with the object of determining the alteration of strength and ductility with changes in the method of welding. With a 26-ton boiler plate used for the shell and its maximum possible strength assumed to be only half this value, it is evident that the actual strength of weld metal, when subjected to a steady tensile pull, is only of small importance compared with other factors. If the ductility of weld metal is below that of the plate, any increase in strength of sound weld metal at the expense of its ductility is to be looked upon as highly undesirable. With fillet welds especially, high local stresses exist, and the greatest possible ductility is the most important requirement.

Izod and Brinnel Tests.—The Izod test is inclined to be variable owing to the liability of weld metal to be porous. It was found, however, to serve a useful function in comparisons of welds that had been given a series of different heat-treatments. In view of the fact that a weld is essentially a casting, cooled at a rapid rate, and has received no mechanical work, remarkably good Izod tests were obtained with high-class welds, of both oxy-acetylene and metallic-arc types. Carbon-arc welds gave distinctly poor results. This form of test is looked upon as of great importance for welds. With welds showing, at the most, only 2 or 3 ft.-lb. energy absorption, it is no wonder objections are sometimes raised to a vessel being hammer-tested under hydrostatic pressure. The results ranged up to 37 ft.-lb. with the specimens only 8 mm. deep in place of the usual 10 mm.

Repeated Impact Tests.—With the machine used, butt-welded specimens that had had the surfaces machined level were alternately deflected by a hammer blow to a distance of 5/32 in. on either side of the center-line.

The test was found to be especially good in picking out inferior welds. Acetylene welds, when judged by this test, were considerably improved by a normalizing treatment. As the tests made form an interesting series, they are given in Table 6.

A conspicuous fact brought out was that with metallic-arc welds the best results, with one exception, were given when welding rods designed to give good forging properties had been used. These welds were, under the microscope, free from contaminations and presumably contained less dissolved oxygen than the remaining metallic-arc welds. Only one oxy-acetylene weld was tested; this showed results intermediate between the forging and non-forging metallic-arc welds. With carbon-arc welds the results were distinctly poor.

Bend Tests.—A very large number of tests was made, as is to be gathered from the fact that the results of fifty-four series of tests were published. The results were divided into three groups: (*a*) acetylene welds; (*b*) metallic-arc welds made with the various forms of commercial welding rod, discrimination being made between the various classes of covering on the rod; welds made by the carbon-arc were added to this list; and (*c*) metallic-arc welds made with welding rods giving good forging properties.

Many comparisons were made of the changes brought about by slight modifications to the manner of making the weld, e.g. the operator was changed, or, with the same operator, the plate thickness was changed, the welding rod was slightly changed, or the weld was compared with another that had been hammered during deposition of the metal.

The comprehensiveness of this portion of the work is to be gathered from the fact that some of the various series of tests involved the preparation and bending of as many as ten or eleven specimens. The samples, unless otherwise stated, had the surfaces levelled before the test, and, as a result of the test, were unbroken. The samples were bent to an inside diameter equal to the thickness of the plate, the object being to make the test drastic, and with single V welds the top of the V was put in tension. The furnace-cooled samples were maintained at the stipulated temperature for one hour, and afterwards slowly cooled. All other heat-treatments were carried out for fifteen minutes. Sample series of tests are recorded in Table 7 (pages 56-57).

With the forge tests the intention was usually to ascertain if the area could be reduced by 50 per cent without cracks being formed; occasionally the test was extended till the reduction of area was greater. Where cracks are reported, they were probably formed at an early stage. The temperature for the annealing treatment was chosen at 950 deg. C. with the object of making the treatment drastic.

No hard-and-fast deductions are possible, owing to variability that occurs with changes in the conditions at the time of welding, and no attempt is made to analyze the results here. Any general conclusion involves the comparison of several results of tests made by different operators. The inferences to which the results tended to point were given in the report, and these distinctly favored the better-class electrodes. A

TABLE 7.—*Showing a few*

Class of weld.	Series No.	Type of weld.	Class of welding rod.	Plate thickness, inch.	As received.	Normalized at 910° C. Angle.
Oxy-acetylene	29	Double V butt (not hammered)	Swedish charcoal-iron rod	½	180°	*130° broken
,,	4	Single V butt (hammered)	Swedish iron rod	¾	42° broken †27° broken	22° broken †65° broken
Carbon-arc	41	Double V butt	Mild-steel filling	¾	63° broken	47° broken 58° broken
,,	51	Double V butt	Mild-steel filling	⅜	3° broken	25° broken
Metallic-arc (ordinary commercial rod)	50	Single V butt	Rod with light wash	½	32° broken	16° broken
,,	44	Single V butt	Lightly flux-coated rod	¾	75° broken	120° broken
,,	53	Single V butt	Slag-coated and wound rod	¾	165° broken	180° bent and flattened, cracks formed
,,	23	Double V butt	Wound rod	7/16	110° broken 140° broken	160° broken
Metallic-arc (forging rod)	54	Single V butt	Slag-coated rod of special composition	¾	160° broken 180°	180° bent and flattened
,,	52	Single V butt	Special wound rod	¾	170° broken	180° bent and flattened
,,	16	Open butt	Wound rod of special composition	¾	150° broken	150° broken

* Local defect.

bending test, taken alone, does not necessarily pick out the most suitable type of weld for a pressure vessel.

Variability of Welds.—An oft-repeated platitude is that a fusion weld depends entirely on the human element, and for that reason it is to be

Representative Bend Tests.

Furnace cooled from 950° C. Angle.	Air-cooled from 650° C. Angle.	Water-quenched at 910° C. Angle.	Water-quenched at 650° C. Angle.	Bent at 910° C. Angle.	Forged between 950° C. and 850° C. Reduction of area per cent.	Forged between 950° and 850° C., and afterwards bent cold. Angle.
180° bent and flattened	180°	160° broken	110° broken	180° broken	50	180° bent and flattened
80° broken	28° broken	*6° broken	—	—	50	180° bent and flattened
70° broken	—	40° broken	—	45° broken	5 broken	—
12° broken	5° broken	18° broken	2° broken	—	50	140° broken
33° broken	—	5° broken	—	—	5 broken	—
150° broken	90° broken	37° broken	40° broken	45° broken	40 broken	—
180°	180°	80° broken	80° broken	12° broken	25 broken	—
180° broken	180° broken	36° broken	—	42° broken	36 broken	—
180° bent and flattened	180° bent and flattened	180° broken	—	180° bent and flattened	64	180° bent and flattened
180° bent and flattened	180° bent and flattened	125° broken	180° bent and flattened	180° bent and flattened	50	180° bent and flattened
—	150° broken	100° broken	—	—	50	180° bent and flattened

† Weld metal at surfaces not levelled.

shunned. There is, therefore, a pronounced tendency amongst engineers to treat all fusion welds under a single heading, irrespective of details of manufacture. Though at present there must always be a certain variation in the quality of even a high-class weld, that is no reason why no

attempt should be made to determine the extent of that latitude, and to design accordingly. So long as the user lays down no standard for the methods of carrying out the work, he must expect to get variable results. Though the attempt at classification is not easy owing to the number of variables, it was felt that they could be limited one by one, and a first effort in this direction has been made by a study of the results obtained with representative electrodes. The setting up of further or improved standards should result in the margin of 50 per cent being reduced to a considerably lower figure.

Electrodes.—As a weld in a pressure vessel is often subjected to severe conditions of service, it was deemed that the most suitable electrode is one capable of imparting properties most nearly approaching those of the plate, while being at the same time as fool-proof as possible. It was not considered satisfactory that a high-class steel should be used for a pressure vessel, and at the same time that the worst quality weld metal should be allowed. The toughness and ductility should clearly be as great as possible.

The results to be obtained by use of representative electrodes were studied, and as a result a list was given tabulating the properties recommended for electrodes to be used with pressure vessels. It will merely be recounted here that electrodes producing welds with good forging properties were in general found to give the best all-round test results, the principal cause of this being probably that the welds were less contaminated with oxygen. Electrodes should, therefore, have good deoxidizing properties, and the weld metal should be protected as far as possible from the atmosphere, both while it is passing along the arc and while it is cooling. Again, on account of its being so common for the operator to bend his electrode, especially when welding at the interior of a confined space, it was deemed of great importance that the covering on the rod should be highly plastic and should not crack when the rod is bent.

Corrosion Tests.—These, in so far as they were carried out, pointed to the superiority of the better classes of electrodes with the welds subjected to acid attack. The carbon-arc welds tested gave inferior results to other forms of weld. Well-made acetylene welds showed up well on test.

Metallurgical Examination of Welds.—Microscopic examination was found to be invaluable in throwing light on the causes of the difference between a good and a bad weld. It was also useful in a study of the changes in weld metal due to its being hammered during deposition, a point that received special consideration during the investigation. Most of the bend samples were examined so that the changes in the microstructure with heat-treatment and the cause of any discrepancies in the test results might be determined. The tensile and other specimens were also examined whenever they showed any abnormality or undue weakness. This work was too voluminous for publication, but the chief points of interest were given in the report.

The changes in structure that can be caused by contamination of weld

metal by the atmosphere formed a study of interest, and, in the hope of reaching a closer understanding of these structures, experimental welds were made in both oxygen and nitrogen, and the results of the experiments recorded.

The macrostructure of welds was found useful in giving information on the method adopted in depositing the metal, on the exact position and shape of the weld metal, and on the amount of penetration of the metal into the plate. Sulphur prints also gave useful information.

Metals, other than Mild Steel, used for Pressure Vessels.—The mechanical and metallurgical features of weld metal, deposited in various plates other than steel, were determined where it was considered that useful information could be obtained. Certain austenitic chrome-nickel steels and cast irons received the most attention, and a few examinations were made of copper and aluminum.

Prints and Microphotographs.—A large number of macroprints, sulphur prints, and microphotographs were made.

Conclusion

The manufacturer of fusion-welded vessels has been content, in the past, that all official regulations should be prohibitive, not constructive. For his craft to prosper his best hopes lie in the existence of regulation, conformity to which will enable a vessel to be recognized by an inspecting authority as being suitable for certification. By conformity to regulations, the adoption of high-class methods of construction, and the use of well-designed intermittent cover straps, there seems no reason why, in the near future, the construction of an unfired pressure vessel should not be extended, with safety, to considerably larger sizes than are indicated in the tentative rules that are appended.

This country has already the workmanship and material necessary for manufacturing vessels of equal or even better quality than are made abroad. Where it lacks is in methods of design and general technique. The labor and the money that have been freely expended in carrying out the investigation will have been well spent if, as a result, a recognized and unbiassed public body places the fusion welding of pressure vessels for land practice on a sound engineering basis.

Acknowledgment.—To the management of his company, the British Engine, Boiler, and Electrical Insurance Company, on whose initiative the investigation was inaugurated, the author wishes to tender his thanks for permission to publish the subject-matter of this paper. To his colleagues, for their help and advice in overcoming many difficulties, to The Ocean Accident and Guarantee Corporation for their kind collaboration and helpful suggestions toward the rules, to Mr. Llewellyn for his invaluable assistance in carrying out a large portion of the mechanical tests and metallurgical study, and to the manufacturers of electrodes and welded constructions for the information and samples of their products, without which the investigation could not have been carried out, the author's thanks are also due.

APPENDIX

Provisional Rules for Fusion-Welded Non-Fired Pressure Vessels

A large number of tentative rules governing the construction of fusion-welded vessels has been framed. As the rules do not purport to cover requirements for a vessel when in service, attention is particularly drawn to the necessity for a vessel to be so situated and so equipped with sight-holes that both sides of all welded seams are readily accessible for inspection; the construction should also be such that all plate thicknesses can readily be gaged. A welded vessel should not be installed where the owner is unable, owing to exigencies of service or other cause, to grant facilities for inspection and hydrostatic test.

Amongst other important requirements are that a drain should be fitted at the bottommost point of a pressure vessel, and that a relief valve be mounted in an approved position, which in general will be on the vessel itself.

The rules are as follows:

(1) *Scope of Rules.*—The rules apply to vessels containing air or non-corrosive gas at a temperature not exceeding 600 deg. F., more especially when the diameter does not exceed 36 inches. For vessls with a diameter not exceeding 20 in., the rules do not apply when the working pressure is 30 lb. per sq. in. or less.

(2) *Method of Welding.*—The rules are applicable to vessels welded by the metallic-arc process with a flux-coated electrode or by the oxy-acetylene process.

Note 1. The rule excludes carbon-arc welding, but in special instances, where the design is approved, the carbon-arc process is permissible for the welding of flanges to tubes not less than 5/16 in. thick, and for the welding of dished ends to shell plates that are secured independently of the weld, and that are not less than ⅜ in. thick.

Note 2. It is recommended, especially when the welding has been carried out by the carbon-arc or acetylene process, that fusion-welded parts should be normalized in a muffle furnace. The temperature should be maintained for a quarter of an hour after the article has been heated uniformly.

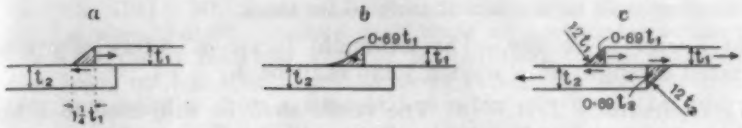
As an alternative, though less effective, where serious damage from scaling or warping would result if it were normalized, the article should be heated uniformly to a temperature of 650 deg. Cent., and then allowed to cool.

Note 3. Mention of the more important properties recommended for electrodes is made elsewhere in the report.

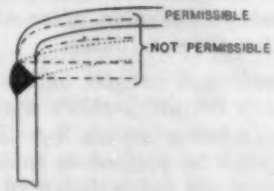
(3) *Strength of Joints.*—The rated strength of a welded joint shall at no time exceed half the strength determined by tests on reasonably well-made joints, made to similar form and subjected to similar stresses.

(4) *Material.*—The plate shall be of boiler-quality mild steel with a nominal breaking strength of 26 tons per sq. in. The strength shall lie between the limits of 24 and 28 tons per sq. in., but it shall be assumed that the strength of the plate when welded does not exceed 24 tons per sq. in.

FIG. 12.

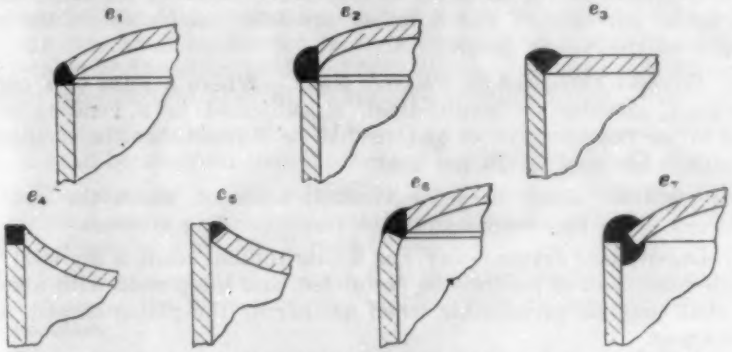


See rule 10 (*a*). *See* rule 10 (*b*), note. *See* rule 10 (*b*), note.



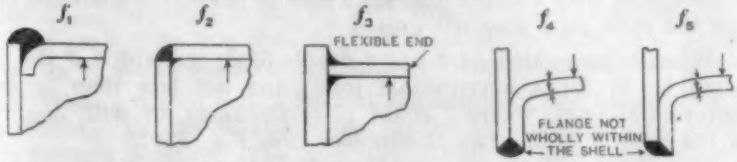
See rule 12 (*c*), note 1.

Other ends not permissible under the heading of "Corner Welds."



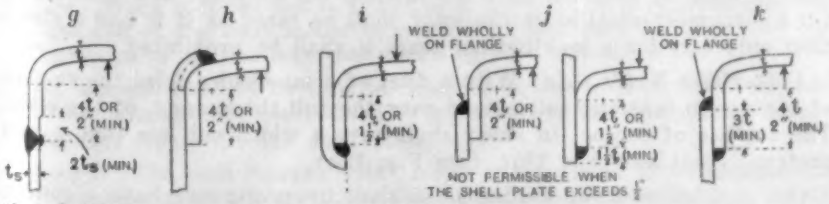
See rule 12 (*c*), note 1.

Other ends not permissible.



See rule 12 (*c*), note 2. *See* rule 12 (*f*).

Permissible ends.



See rule 12 (*i*). *See* rule 12 (*b*), note. *See* rule 12 (*b*), note. *See* rule 12 (*b*). *See* rules 9 (*c*), 9 (*d*), and 12 (*b*).

(5) *Plate Thickness.*—The plate of a welded vessel exceeding 12 in. in diameter shall be not less than 3/16 in. thick.

(6) *Factor of Safety.*—The minimum factor of safety allowable on the rated strength of a welded joint shall be 4.

(7) *Hydrostatic Test.*—(*a*) The vessel shall be subjected to a hydrostatic test at not less than twice the working pressure, during which it shall be subjected to a hammer test; the pressure shall then be reduced by more than 50 per cent of its value, after which it shall be again raised to the original value for three minutes.

(*b*) The hammer test shall consist of the plate on both sides of all welds being struck sharp vibratory blows with a hammer not less than 2 lb. in weight, the blows being struck 2 to 3 in. apart and close up to the seam. The blows shall be applied as rapidly and heavily as possible, consistent with the metal not being indented or distorted.

(*c*) When the factor of safety of the vessel exceeds 4 the test pressure shall be 50 per cent of the bursting pressure, calculated on the rated strength of the welded joints.

(8) *Stresses Imparted by Flexible Ends.*—Where a joint or a portion of a joint, circular or longitudinal, is subjected to a bending action owing to the flexibility of an end, it shall be deemed that the strength of the joint is reduced by 10 per cent.

This shall not apply to a longitudinal seam of which the ends are reinforced in an approved manner to resist bending stresses.

(9) *Lap-Welded Joints.*—(*a*) For a longitudinal seam, a lap weld with a single fillet shall at no time be permitted, and a lap weld with a double fillet shall only be permissible when neither of the plates exceed $\frac{3}{8}$ in. in thickness.

(*b*) For a circular seam or for affixing an end plate when the shell plate is not constricted, i. e. turned in over the flange of the end plate, a lap-welded joint with a single fillet shall only be permitted when the thickness of the shell plate does not exceed $\frac{1}{2}$ in.

(*c*) When a lap-welded joint has a double fillet, the width of the landing shall be $3t$ for a longitudinal joint, and not less than $3t$ for a circumferential joint, where t is the plate thickness, or with dissimilar plates the greater of the two thicknesses (*see* Fig. 12*k*).

(*d*) When a lap-welded joint has a double fillet the internal fillet shall be accessible for inspection. Where there is no ready means for inspection it shall be assumed that the fillet is nor-existent, and accordingly for a circumferential seam the joint shall be rated as if it had a single fillet only and for a longitudinal seam it shall be prohibited.

(10) *Fillet Welds.*—(*a*) With a fillet of a lap-welded joint the surface of contact in tension shall extend over the full thickness t_1 of the plate. The surface of contact in shear shall have a width not less than t_1 and preferably not less than $1\frac{1}{4}t_1$ (*see* Fig. 12*a*).

(*b*) A fillet of a lap-welded joint shall by preference have a convex profile. At no time shall the thickness at the throat be less than 0.69 times the plate thickness t_1.

Note. The throat thickness is defined as the minimum depth of the weld (*see* Fig. 12*b*). Where the two contact surfaces of a fillet are equal, the rule requires that the contour shall show no appreciable concavity; a minimum throat thickness of $0.69t$ is equivalent to the radius of the fillet being not less than $12t$, which gives an approximately straight contour, the deviation from a straight line being only $0.02t$ (*see* Fig. 12*c*).

(*c*) With a fillet weld affixing a fitting to the wall of a vessel or a pipe, the throat shall have a minimum thickness of $0.58h$, where h is the minimum height allowable for the surface of contact in shear.

Note 1. Where the two surfaces of contact of the fillet are equal, this throat thickness is attained by a fillet with a concave profile and a radius equal to $2h$, the deviation from a straight line being $0.13t$.

Note 2. The value required for the dimension h depends on the details of the design and manufacture of the joint. In general the total height for a branch tube should equal $3t$, where t is the thickness of the branch tube.

(11) *Butt-Welded Joints.*—(*a*) When the diameter of the vessel does not exceed 24 in., the strength of a butt joint with the plate welded at only one side shall be deemed to be reduced to half the strength of a butt joint with the plate welded at both sides. For larger diameters this form of construction shall at no time be permitted.

(*b*) When the inside surface of a butt joint is not accessible for inspection, it shall be assumed that the plate is welded at one side only.

(*c*) The edges of a plate jointed by a butt weld shall be bevelled, and the included angle of the weld metal shall be not less than 90 deg. for either a single or a double V weld.

Note. It is recommended that the total depth of reinforcement at the two surfaces of the plate should be not less than 25 per cent of the plate thickness.

(12) *Design and Attachment of Dished Ends.*—(*a*) A dished endplate shall have an inside radius not greater than the internal diameter of the shell. The thickness of metal shall be such that the working pressure or the allowable stress to comply with rule 13 is not exceeded, but in no instance shall it be less than the thickness of the shell, and for vessels exceeding 12 in. in diameter the minimum thickness shall be ¼ in.

(*b*) When a dished end is flanged, the length of the flange shall be not less than 1½ in. for an end convex to the pressure, nor less than 2 in. with the end concave. The minimum length of the flange shall at no time be less than four times the thickness of the plate. An increase above these specified minimum values is desirable. (*see* Figs. 12*j* and *k*.)

Note. When a dished end is affixed by a lap joint, it is recommended that the end of the shell should be constricted, and that the degree of constriction be not less than that shown by Figs. 12*h* and *i*.

(*c*) An end shall at no time be fixed by means of a corner weld, and, where a flanged end-plate is fixed by a butt joint, the flange shall form a continuous line with the shell plate.

Note 1. The term "corner weld" refers to any form of weld, where the flange forms an angle with the shell plate; this is illustrated by Fig. 12*d*. Any similar constructions without flanges, such as those shown by the drawings Fig. 12e_1 to e_7, are also prohibited.

Note 2. Several other undesirable forms of end are constructed, e.g., those shown by Fig. 12*f*. These are not permissible, nor is any form of flexible end, the breathing of which imposes a direct bending stress on the weld.

(*d*) An end plate with reversed curvature shall at no time be permitted.

(*e*) The inside radius at a knuckle shall be not less than four times the thickness of the end plate or not less than 1½ in., whichever is the greater.

(*f*) An end plate convex to the pressure shall be driven into the shell so that the end of the flange lies a distance not less than one-and-a-half times its thickness within the shell.

(*g*) When a dished end of a thickness greater than that of the shell is affixed by a butt joint the end of the flange shall be reduced to the thickness of the shell for a length not less than twice its thickness. (*see* Fig. 12*g*.)

(13) *Thickness of Dished Ends.*—(*a*) With an end concave to pressure the working stress calculated by the formula $\frac{pr}{2t}$ shall be not more than 6000 lb. per sq. in., irrespective of the general factor of safety adopted for the vessel.

(*b*) With an end convex to the pressure, welded to the shell, the allowable pressure shall be not more than the bulging pressure p (calculated by Bach's formula $p = \frac{t}{r}\left[\ 73{,}958\text{-}3{,}272\sqrt{\frac{r}{t}}\ \right]$) divided by a nominal factor of safety against bulging that is 25 per cent higher than the desired factor of safety, the value of which is named in the following table.

In the event of r/t having a value lower than that given in the last column of the table, the thickness of the end shall be such that the stress calculated by the formula $\frac{pr}{2t}$ shall be not more than 5000 lb. per sq. in. irrespective of the general factor of safety adopted for the vessel.

Designed Factor of Safety of vessel	*Nominal Factor of Safety against bulging to be used for a welded vessel with Bach's formula*	*Lowest value of r/t with which the working pressure shall be determined from Bach's formula*
4.0	5.0	53.6
4.5	5.625	29.3
5.0	6.25	12.3

Building an All Welded Oil Storage Tank by Arc Welding

By I. S. Dmitrieff, Vladivostok (Siberia)

THE Searching Laboratory for Welding of the Far-Eastern State University at Vladivostok is intended not only for studying purposes, but also for practical work. The laboratory received an order for building a benzine storage tank by the arc welding process. The tank was

supposed to be of 300 tons capacity, of cylindric shape with a conic roof, its diameter was to be 26 ft., height 21 ft. 3 in., thickness of the roof 3/16 in., wall shell ¼ in. and the bottom ¼ in., too. The time of delivery agreed upon was five weeks.

The tank in question was to be erected far away from the town in an absolutely wild country, where the normal conditions of work were excluded. No power was available for driving the welding generator, so that the latter was to be driven by a portable locomobile taken from the Laboratory.

FIG. 1—THE WALL SHELL SHEETS ROLLED UP FOR THE TRANSPORT

When making out a general plan of work we could not find any practical advice in modern technical literature that might give us a few hints as to how to manage the work under such difficult circumstances and we had therefore to find some method for solution of this complicated problem.

Owing to the scarcity of time all the work to be done was divided into two parts, namely, first all the preliminary work, welding and assembling single parts of the tank, etc., has been done at the laboratory. At the same time building of foundation was carried on at the place of destination. Thereupon the parts were forwarded by rail to be connected up and welded on the spot within the following three weeks.

With regard to the transport it is to be pointed out that the dimensions of single packages were subjected to special prescriptions and rules of the railway.

All the seams of the bottom and of the roof, except middle ones, were welded at the laboratory. The wall shell sheets were butt welded in form of single ribbons that were rolled up for the transport and had a diameter of 9 to 10 ft. (Fig. 1). The whole tank was divided into nine parts to satisfy the prescriptions for the railway transport. The half parts of the roof were tack welded with the half parts of the bottom, so

that they had the form of a fan that was put on a platform-car in vertical position.

When loading this "fan" we had accidentally an opportunity to examine the seams welded by the arc process. When the "fan" was already on the platform-car and there remained nothing but to get it properly fastened, it was thrown down by the hoisting crane through the careless attendance of the latter and fell onto pieces of channel iron put near the car.

The total weight of the "fan" was about 5 tons, and its upper point was about 18 ft. above the ground. The upper part of the "fan" was

FIG. 2—WELDING THE MIDDLE SEAM OF THE ROOF

not damaged at all, while the part of the roof that was underneath lost its conical shape and became quite flat.

In order to get it fixed up again, a special platform of wooden planks was made. The half-bottom was placed on same and covered with the half-roof that became flat. Then the top of the roof was attached to the hoisting crane and lifted up, whereupon the roof regained its initial conical shape; in this position it was kept by the crane until it was tack welded with the angles of the bottom. A careful examination of seams showed that they had no defects whatsoever.

According to our plan of work and under consideration of the above-mentioned exceedingly difficult local conditions our work was carried on not quite in the usual way.

By the time when the last parcels of tank parts were received at the place of destination, the sand foundation was already evened, temporarily covered with wooden planks, on which there were put some pieces of rails. The "fans" have been put on the rails, and we got the middle seam of the roof welded (Fig. 2).

When both half-parts of the roof were welded together, the whole roof was lifted up by means of 4 hoisting tackles to the height of one drum that was welded together with the angles of the roof. Thereafter the roof together with the welded on drum was lifted up as before to the height of the next drum that was welded together with the previous one, and then the same process was done again for the next drum. This

method enabled us to do all our work directly on the ground and to avoid application of auxiliary timber building.

For lifting up the tank four wooden pillars were put at the end points of two crossing diameters at a distance of about 3 ft. 4 in. from the tank bottom; we took for this purpose about 16 ft. high pillars with iron rings fastened on the top; the hoisting tackles were turned toward the tank and the pulleys were on the opposite side.

The roof was easily lifted up by four people to the height of 5 ft. A manhole was made in the bottom. The rolled up sheets were brought in, put onto the bottom and unrolled. When examining same, we found besides some small dents five rather heavy ones, which was evidently the result of careless loading and unloading.

FIG. 3—HOISTING THE ROOF TOGETHER WITH THE FIRST DRUM

In order to get the bigger dents fixed, they have been hammered against one or two pieces of rails held on the back-side. Thereafter the sheets were folded by means of staples from the middle to the ends with the angles of the foundation and tack welded with the intervals of about 8 to 10 in. After having tack welded all way round we made the necessary final corrections by means of staples, which work and staples can be seen in Fig. 5.

When the upper horizontal edge of the drum was fixed, the roof has been lowered down and its angles were fixed inside the first drum (the drums to be counted downward from the top) by means of picks, chisels and ⅛ in. thick iron plates. In order to facilitate the welding process, ¾ in. clearance was left between the upper edge of the drum and the horizontal flank of the angle. All this work required ten days of work.

After having welded both horizontal and vertical seams, the drum was hammered all way round three times from inside just by the lower edge against the angles of the bottom and a piece of rail iron held from outside. This was done in order to get the lower edge of the drum properly hardened, thus maintaining the cylindrical shape.

Thereupon all the tack welds were cut out, and the roof with the drum was lifted up by hoisting tackles to the height necessary for the treatment of the second drum (Fig. 3).

All the following drums have been treated in the same manner as the

first ones. Six plumb-lines were sunk down from the roof to examine the verticalness of the wall shell.

The horizontal outside seams were welded in downward direction from one side only, and in the upward direction (overhead welding) they were ⅜ in. tack welded with the intervals of 1 ft. 8 in. The vertical seams have been welded from both sides.

The initial plan was to lay out the sheets as shown on the left hand side of Fig. 4, but in the course of work it was decided to make all the seams outside, as on the right hand side of Fig. 4. This has been done for following reasons: (1) All the eventual defects of welding can be much easier found out when testing; (2) The tank looks generally much

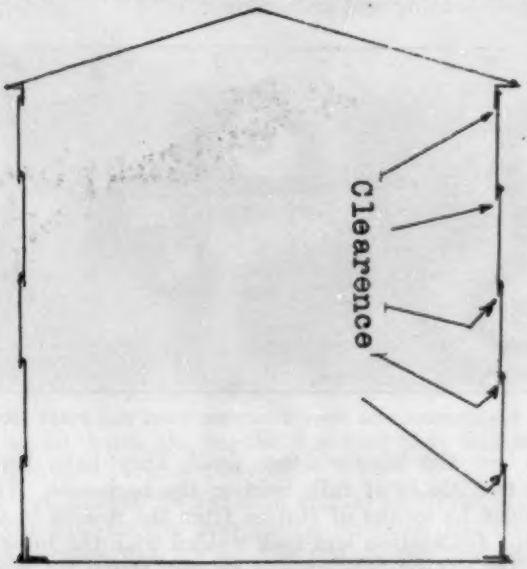


FIG. 4—CLEARANCE BETWEEN THE EDGES INSIDE THE TANK

cleaner, all the seams are being nicely welded; if we followed our initial working plan, we would have two seams inside, and traces of tack welding would spoil the appearance of the tank; (3) In case the inside seams might become leaky, then it would be rather hard to find the leaky place, and after testing we should have to open the manhole, to ventilate the tank and make special arrangements for the access to the leaky seam to be welded.

The roof with the first drum attached was lifted up by means of staples fastened on the roof by welding (Fig. 3).

For fixing the third drum, the staples were removed and placed between the first and the second drums (Fig. 5). As the seam in question was sufficiently hard, no precautionary measures have been taken to prevent distortion of the drum from tension of places, where the hoisting tackles were fastened.

In order to lift up the third and the fourth drums, staples were fixed not between the second and the third drums, but 10 in. above the lower

edge. In this case there was considerable danger of deformation, and therefore the following precautionary measures were taken: four steel bars were fixed by welding cross-like inside the tank and in addition, opposite those places where the staples were fastened from outside, angles were welded on from inside, so as to make the wall shell more resistant to distortion.

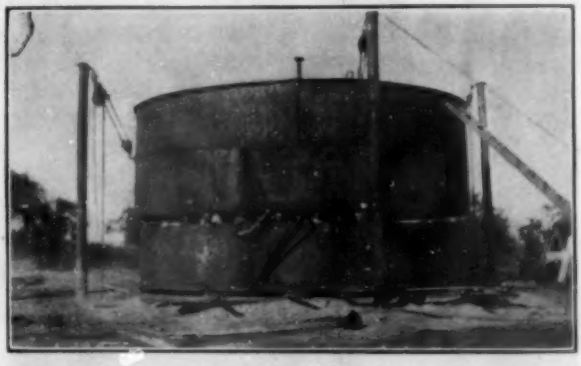


FIG. 5—STAPLES FASTENED FOR FIXING THE THIRD DRUM

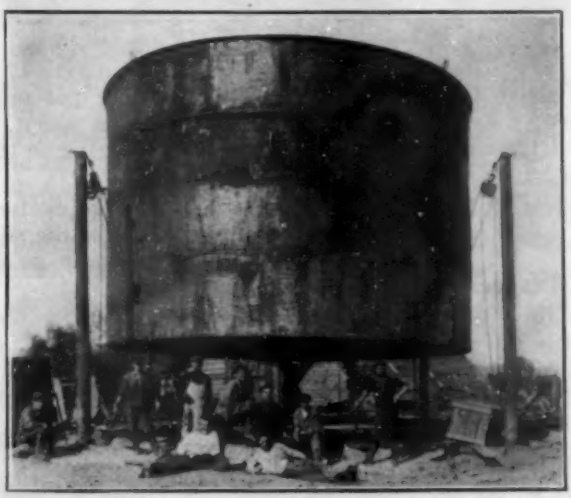


FIG. 6—ARRANGEMENTS MADE FOR HOISTING THE THIRD AND THE FOURTH DRUMS

When the fifth drum was finally welded, it was provided with two holes—one manhole and another one for the inlet pipe. Thereupon the hole that was previously made in the bottom for getting into the tank was not necessary any more and it was therefore covered with a disc provided with a discharge pipe; the disc was likewise fixed on the bottom by arc welding.

It was first decided to get the tank tested by filling it with kerosene and water while it was hoisted and rested on the supports, but after having

tested the bottom with kerosene, the whole tank was lowered down, put on its foundation and then it was filled with water.

The tank was hoisted by means of four hoisting tackles and four screw-jacks placed between these tackles; the tank was lifted up to the height of

FIG. 7—ALL WELDED TANK

about 3 ft. above the ground. The supports were put only along its circumference; between single supports there was about 6 ft. 8 in. space, so that the whole bottom was practically hanging in the air. This job required 28 hours of work.

Three barrels of kerosene were poured out onto the bottom, and then the latter was carefully examined 24 hours later. Not the slightest leakage could be found. Although the bottom was in the air, as already mentioned, it had no considerable outward bent.

When the tank has been lowered down, filled with water up to the upper flange in the center of the roof and kept so within 8 hours, it did not show any leakage at all. Only one slightly wetted spot has been found on the roof and seven such spots on the wall shell, which was immediately fixed by caulking. When the tank was emptied after testing, which took about 3 hours, the caulked places were additionally welded.

Fixing each drum took on the average about 72 hours and was completed by 4 to 6 common workmen during the first 36 hours. Fixing staples and steel bars required each time 4 hours for one welder and one common workman. One day was spent for welding a seam between the drums, one day for welding the seams of the roof, one day for welding the seams of the bottom and one day for fittings. This makes in all 19 days spent for building this all welded tank (Fig. 7).

The above tank is now in use and our clients have no complaints whatsoever. The laboratory has received an order for another 13 similar tanks. It is expected that this number of tanks will enable the laboratory to cut considerably its expenses and make a reduction for the clients of some 10 per cent or even more.

The First Arc-Welded Bridge in Europe

By Stefan Bryla†

THE first arc-welded steel bridge in Europe has been erected for the Polish government in Lowicz, Poland, and crosses the Sludwia River in a single span 88½ ft. between supports. It is located on the principal state highway between Warsaw, Poznan and Berlin. The total width of the bridge is about 32 ft. 9 in. and the distance between the trusses is 20 ft. 4 in. Sidewalks 6 ft. wide are cantilevered out on either side.

The design calculations were made in compliance with the specification of the Polish Ministry of Public Works, issued in 1925. The material used in the bridge is mild steel with an ultimate strength of 55,000/60,000 lb. per sq. in. and with a minimum elongation of 20 per cent. The allowable unit stresses were 16,000 lb. per sq. in. for the trusses and about 12,000 lb. per sq. in. for the floorbeams and stringers. Mild steel electrodes with an ultimate strength of 55,000/60,000 lb. per sq. in., containing a minimum of 0.1 per cent carbon and 0.25 per cent manganese, were used. Elongation, bend and shearing tests were required of all welders.

Details of the Bridge—The trusses of the bridge are of camel-back outline, having a span of 88½ ft. and a height in the middle of 14 ft. All members of the trusses are built up of plates, channels and angles, as shown in the accompanying drawings. The chords are built up entirely of plates. The diagonals consist of two channels turned to the outside and joined with coverplates top and bottom, while the vertical members are made up of a single plate and four flange angles. The crossbeams are plate girders constructed entirely of flat plates with no flange angles.

I-beams are used as longitudinal stringers and are welded to the cross-girders by trapezoidal plates, not only for the purpose of connection but also to stiffen the web of the cross-girders. This detail, shown in Fig. 3, permitted the calculation of the stringers as continuous beams on elastic supports. While the elasticity of the supports diminishes the advantage of continuity, it draws the crossbeams into cooperation and allowed a saving of 12 per cent in the material of the crossbeams. However, this saving is possible only if there are one or two concentrated loads sufficiently large in comparison with the other loads, a contingency foreseen by the Polish specifications.

All the welds of the plates are butt welds. In the calculations it was assumed that these welds had only 75 per cent of the resistance of the base material. The wind bracing consists of angles welded to horizontal gussets which are attached to the lower chords of the main trusses and to the crossbeams.

Building the Bridge—Pieces up to 23 ft. long were welded in the shop.

†Professor of the Technical University, Lwow, Poland.

Special jigs (Fig. 6) were used at about 3-ft. intervals to hold the pieces firmly together. In one instance these jigs consisted of ¾-in. round bars bent according to the cross-section of the pieces to be welded. Two

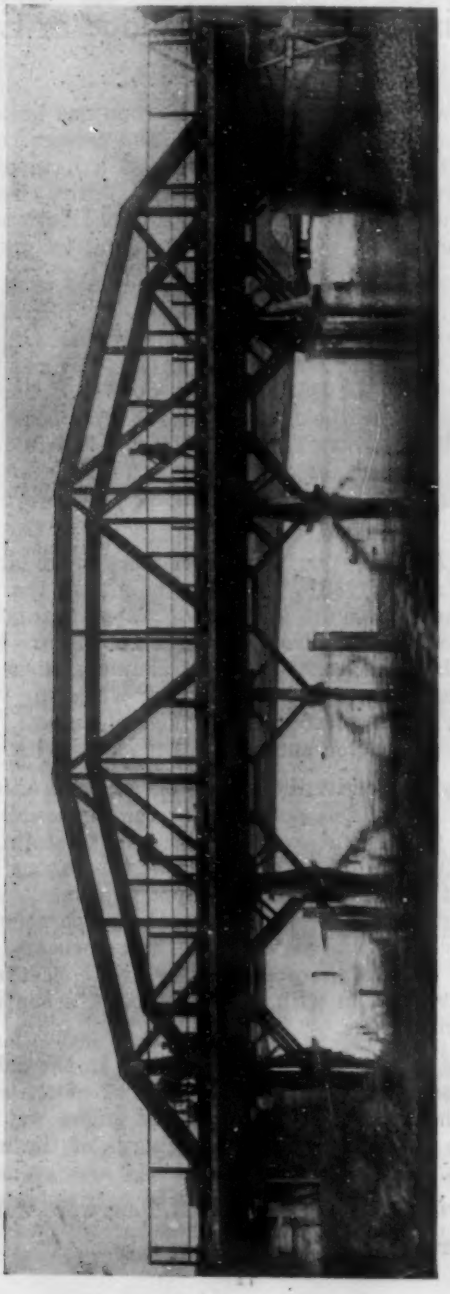


FIG. 1.—ARC-WELDED HIGHWAY BRIDGE IN EUROPE
Falsework is still in place

gussets were welded to the inside of these bars with a crack of about 2 in. left between the gussets. The width of this crack was regulated by means of two angles in such a way as to admit the vertical plates of the bridge member with close clearance.

In the jig for the upper chord, which has a double-T section, channel spacers were placed between the vertical plates of the chord. Between the gussets and the flanges of these channels a crack about 1 in. wide was left to permit free access of the electrode.

FIG. 2—WELDING AN END POST ON THE POLISH HIGHWAY BRIDGE
Note the welding generator in the foreground

FIG. 3—WELDED CONNECTION BETWEEN STRINGER AND FLOORBEAM
Adoption of this type of connection permitted calculation of the stringers as continuous beams and resulted in a saving of about 12 per cent of steel in the crossbeams

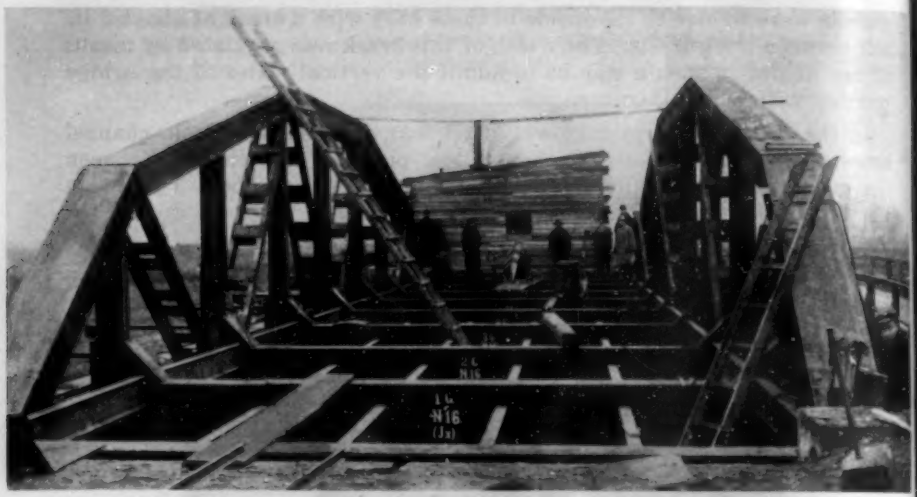


FIG. 4—WELDED HIGHWAY BRIDGE IN POLAND NEARING COMPLETION

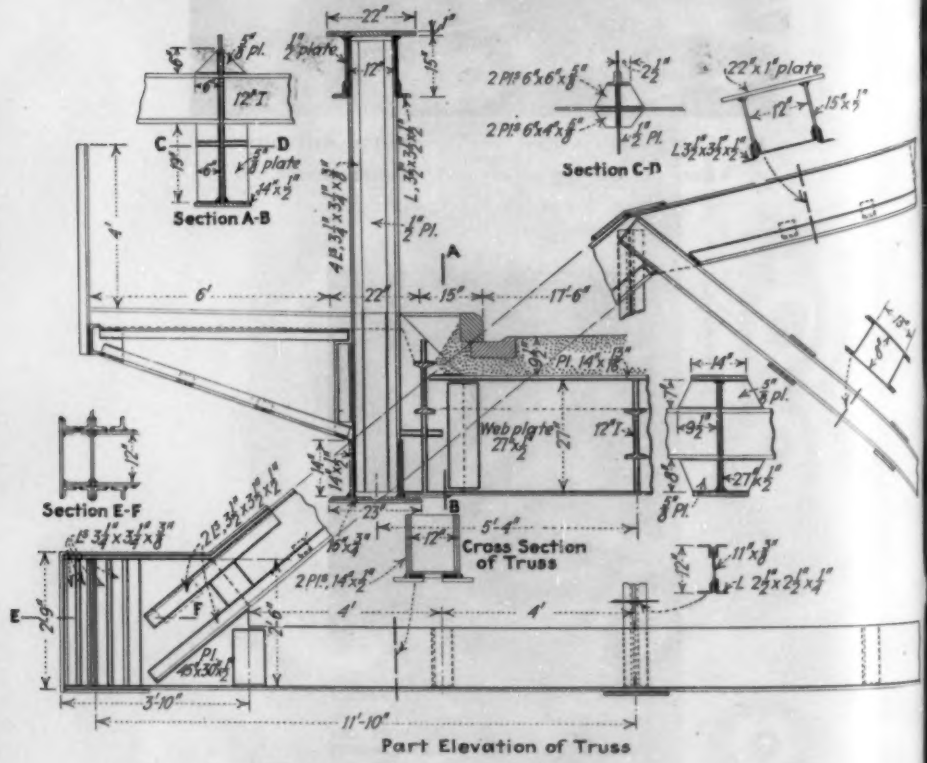


FIG. 5—STRUCTURAL DETAILS OF WELDED HIGHWAY BRIDGE IN POLAND

The vertical members, consisting of a plate and four angles, were assembled by the aid of two screws on both ends and some short welds along each vertical. The two channels of the diagonal members were assembled by means of plates cut as shown in Fig. 6D. The cross-girders were constructed by the aid of the jigs shown in Fig. 6C and similar to those employed for the chords.

Current of 180 amp. and 30 volts was used in the field. Hand welding was resorted to, utilizing flux-covered electrodes. Assembling in the

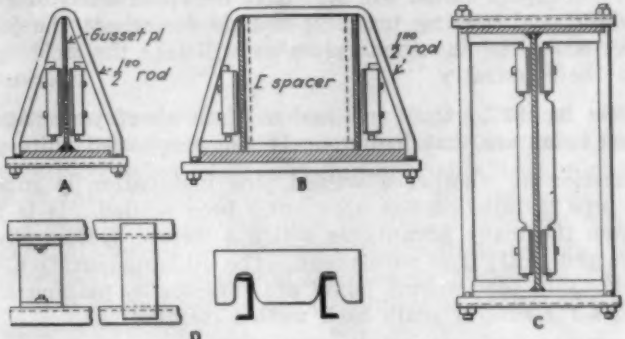


FIG. 6—JIGS USED IN FABRICATING MEMBERS FOR WELDED BRIDGE IN POLAND

field was done on a temporary wooden trestle, all of the steel being erected by means of a wooden crane. The work began by placing the floor of the bridge and later the main trusses. Three welders were employed in the field.

The design of the bridge was executed by the writer, who also had supervision of the construction and erection. The total weight of the bridge is 55 tons, while the riveted design would have weighed 70 tons. Unfortunately there was not an equal saving in the cost of the bridge, because the amortization of the cost of the necessary arc-welding machines had to be included in the cost of the bridge. As a consequence the arc-welded bridge cost approximately as much as a riveted bridge. Nevertheless, the writer is firmly convinced that in the course of time the proportion of costs of the two types of bridges will be changed in favor of the arc-welded design.

The Needs of the Metropolitan District for Instruction in Welding*

W. F. MCKAY†

S. E. DIBBLE, Professor of Heating and Ventilating at the Carnegie Institute of Technology in a paper entitled, "Welding in Plumbing and Heating," which he read at the convention of the Gas Products Association at Montreal on July 14, 1927, said:

*Paper presented at Annual Meeting, A. W. S., April 25, 1930.
†Chief engineer, International Oxygen Company.

"The question that confronts my mind in this proposition is whether or not the welding torch will ever become a tool in the plumbing and heating industry, and when I speak of 'tool' I mean manipulation or skill. I believe that it will. I believe that the plumber and the steamfitter in time will be using the torch as he now uses the stillson wrench, his hammer and chisel, and other necessary tools.

"I do not believe, however, that the welder, termed as a welder only, will ever break into the plumbing and steamfitting industry. I cannot see where the expert welder will ever have the opportunity of getting into the plumbing and heating trades, but I do see where the journeyman steamfitter and the journeyman plumber will take the welding skill and use it in their industry."

That was in 1927. Only two and one-half short years ago, but the indications today are that Professor Dibble prophesied quite accurately.

The question of whether a welded pipe installation is superior to a threaded pipe installation has apparently been settled. It is difficult to escape from the many advantages which a welded system offers. It is neat; it is practical; it is permanent. The oil transportation companies have clearly said that welded joints are superior by making all of their installations for several years back welded installations.

Subway designers, architects of skyscrapers and power houses, and other engineers have also placed their stamp of almost unqualified approval on welded pipe joints, their attitudes in most cases being prompted by considerations of permanence and freedom from future trouble.

While these considerations are important in themselves, there are others of equal or greater importance.

Proper study has definitely indicated that while the cost of a single welded joint is slightly greater than the cost of a single fitted joint including the fitting, nevertheless, if we consider the job as a whole, we find that a welded installation is more economical than a fitted installation. This apparently contradictory conclusion is caused by reason of the various savings effected by welding including less handling of pipe in and out of vises; greater leeway in taking measurements; the elimination of costly errors and no costly and unusual fittings to supply and often to wait for. In addition there is the great advantage that the elimination of threads allows the use of smaller cross section and thinner walled piping.

From the foregoing it would be logical to assume that welding would be the recognized method of pipe or steamfitting, not only in such applications as have already been described, but also in every phase of the piping industry including even heating systems for individual homes. That it has not as yet reached that eminence is due chiefly to the serious objection that the all-important matter of manpower and skill to do pipe welding has not been developed at anywhere near the speed that the technology has progressed.

I agree with Professor Dibble that the logical development is that our

present steamfitters should be taught the art of welding rather than that welders should be taught the steamfitting trade.

At the present time pipe fitters and welders in New York and other large cities are entirely controlled by the local unions. Because only a few of the members, and certainly not nearly enough to go around, know anything about pipe welding, outside welders not union members are called onto the various jobs causing continual labor disputes; delays in getting the work completed; higher costs on this account, and we can assume some discouragement on the part of the architects and contractors responsible for the specifying and carrying out of the contracts, and possible hesitation on their part in encouraging welded construction on future contracts.

Just as the textile worker in Lancashire, England, looked with suspicion on the spinning jenny when it was introduced to the textile industry and as workmen have acted since time immemorial when any change which might affect their livelihood was suggested, the steamfitters in general have in the past tacitly opposed pipe welding. He opposed it, not because of the fear that welding would replace steamfitting, as was the case with the textile worker, but because of the misapprehension that pipe welding was so difficult as to preclude the possibility of his readily adding it to his list of acquirements.

It might be said here that the welding industry has been very slow to consider the importance of the mental attitude of the steamfitter in this development and it is believed that considerable time has been lost on this account.

Fortunately, however, because of its economic and other advantages, the art developed in spite of opposition to a point where its importance could not be gainsaid and the steamfitters' unions, recognizing the inevitable, are now not concerned so much about pipe welding as a general proposition as they are about how they can get their men trained to do pipe welding.

In the early fall of last year the walking delegate of one of the local steamfitters' unions approached me and suggested that it might be an opportune time to propose pipe welding training for the members to the officials of the union.

A conference with the executive committee was arranged and after considerable discussion of the pros and cons at many other meetings, a decision to organize a school to train their members was arrived at.

As a result the international oxy-acetylene welding school was organized, its prime purpose being to teach the art of pipe welding to the members of a specific local steamfitters' union.

The school is located on Forty-fifth Street, New York City, which is, we suppose, as centrally located as possible, although our experience seems to indicate that location is not of great importance as we have students attending the class from Westchester on one side and from Coney Island on the other, distance not seeming to affect them in their eagerness to step into line in this important development.

Equipment has been provided to train ten students in each class. There are two classes, one class meets on Mondays and Wednesdays; the other on Tuesdays and Thursdays; the hours of attendance being from 7:30 to 9:30; the length of the course being twenty lessons.

A welding table of the conventional type, (structural-steel and fire-brick), has been provided for each student, the tables having been arranged so that they are clear of obstruction on three sides in order that the student may readily get around his work.

Each table is equipped with a full complement of apparatus: A welding torch, acetylene regulator, oxygen regulator, oxygen and acetylene cylinders, and a cutting attachment.

The use of so much equipment might have been avoided by the use of discharging and distributing lines, but the committee in charge of the school decided in favor of individual equipments to insure the student being trained under approximately the same conditions insofar as equipment is concerned as he would meet in the field.

We realized that even with the advantage of good material to work with, it would be difficult to turn out the type of pipe welders we desired in twenty lessons unless the training was very intensive, so the number of students per instructor was kept as low as possible, each instructor being required to handle only five students and as an indication of how few really good pipe welders there are in the city, we might mention here that one of our chief problems was to secure capable instructors.

The course which is taught has been made as simple as possible. The fact that the students are already skilled tradesmen eliminated the necessity of primary instruction in mechanical fundamentals.

We did, however, stress the importance of flame adjustment, giving the student an intensive session on this point alone and the understanding of proper fusion of the metal, which the students practised before they began to weld.

The metallurgical factors of welding are discussed only when necessary and as seldom as possible. The average student appears to dislike what he refers to as "Book Learning" and "Blackboard" work and we agree with him that his knowing that the volumetric content of an oxygen cylinder is 1.54 cubic feet and that an acetylene cylinder has a monolithic or asbestos filler or knowing the chemical reaction which takes place when oxygen and acetylene are burned at the end of a welding torch tip is not going to help him make a good weld nor is his lack of that knowledge going to warrant his believing that he will make a bad one.

As mentioned before in this paper, the course will be as simple as possible. The student will first be taught to make a perfect ripple weld with two pieces of ¼ in. x 2 in. steel.

When this has been accomplished to the satisfaction of the instructor, He will be given two pieces of 2½ in. pipe to butt weld and this will be continued until he can make such a butt weld of suitable appearance which can stand a 250 lb. pressure test.

The next study will be to weld a 2 in. branch into a 4 in. pipe in a

horizontal position with the branch on top. Next he will be given the same study with the 4 in. pipe in a vertical position with the 2 in. branch as a side outlet.

Next, in order to get practise at overhead welding, the 4 in. pipe will be again placed horizontally with the 2 in. pipe appearing as a branch underneath.

Finally, on the last evening of the course, a moving picture exhibit showing the many varied applications of pipe welding will be given in order to show the student how and where pipe welding may be practised.

Our premises in regard to the method of procedure required to teach the student to make a welded pipe joint may be open to criticism, but when it is remembered that all we are endeavoring to do is to show him how to substitute a welded joint for a screwed joint, consideration will show that our program covers the subject.

Since we became active in this work some interesting facts indicating the interest in pipe welding in our immediate locality have come to our attention.

The Essex County Manual Training School at Newark, N. J., has opened a class to teach pipe welding to plumbers and steamfitters.

A class of the same nature is contemplated by the educational authorities at Elizabeth, N. J., and at New Brunswick, N. J.

The New York State Board of Education already have evening classes of the same nature at:

Buffalo	with	130 Students
Binghamton	with	22 Students
Ithaca	with	10 Students
Niagara Falls	with	70 Students
Rochester	with	30 Students
Syracuse	with	80 students
Schenectady	with	32 Students
Watertown	with	10 Students

Similar classes will be opened next fall at Albany, Auburn, Dunkirk, Elmira, Jamestown, Lockport, Utica, and Yonkers; and, I am informed by Mr. Jay E. Crowley of the adult education bureau of the New York State Education Department that similar classes will be inaugurated in other representative cities as the opportunity and demand occurs.

That interest in this direction is not confined to the particular territory which I have covered. I am told that there are 500 men attending pipe welding classes at the Carnegie Tech in Pittsburgh and no doubt some of you gentlemen can tell us where other educational effort along the same lines is going on or in contemplation.

It behooves every member of this organization and the organization as a whole to cooperate with those sponsoring training in pipe welding and particularly with those municipal county and state education groups who are organizing evening continuation classes for this purpose, in order that pipe joint welding will become an accepted fact and that this great and important industry of ours will advance and progress.

Production Welding

DE W. ENDICOTT[1]

THE oxy-acetylene process is being used today as a standard production method in a variety of industries, because it fulfills nearly all the conditions that could possibly be desired by the manufacturer or the production engineer. The vital factor which has led to the adoption of this process for the manufacture of such a wide range of products has been the ability to turn out a better product at a lower production cost. For some time after its introduction, welding seemed to the production manager to be so different from ordinary fabricating methods which had been in use for a long time that its adoption as a production tool was somewhat delayed. Today, however, the widespread knowledge of the process combined with new developments in managerial control of welding has made the oxy-acetylene process a recognized, universal production tool. Leaders of industries who at first hesitated to apply

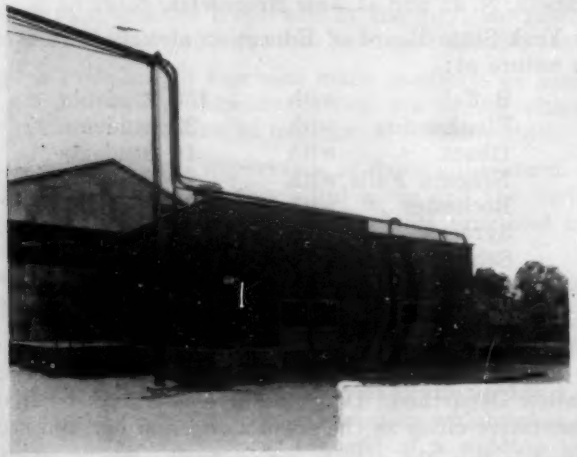


FIG. 1—GENERATOR HOUSE WITH WELDED DISTRIBUTION PIPING

welding are now among the foremost enthusiasts over its growing use. One need only note the number of products formerly turned out by other methods which are today fabricated by welding to be convinced of the merits of this method.

Many factors have contributed to this increase in production welding, and it will be the purpose of this article to consider some of them, citing certain examples in the more important and more familiar industries.

[1] Publicity Dept., Union Carbide Company.

Facilities for Production Welding

An important reason for the use of welding in production work has been the adaptability of this process to large-scale operations. Oxy-acetylene facilities are easily installed in any plant and their maintenance is a simple matter. The facilities for quantity production using the oxy-acetylene process are designed to effect the greatest possible economy in operation.

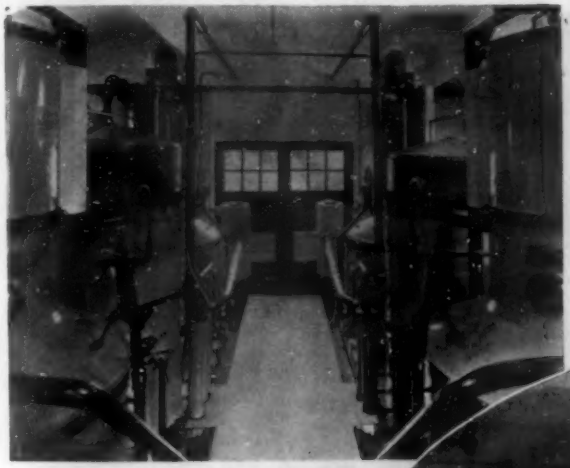


Fig. 2—Duplex Generators Supply Acetylene for Production Work

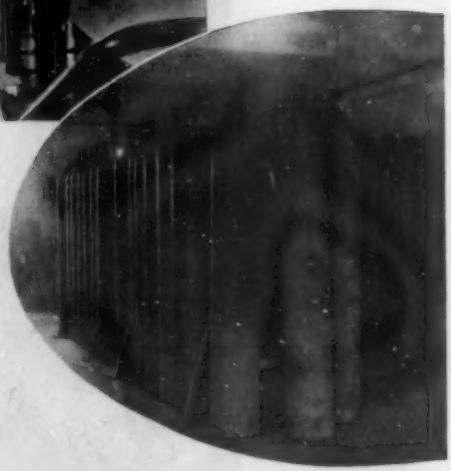


Fig. 3—Oxygen is Supplied From Manifolded Cylinders

In large production plants, acetylene is generally supplied by large acetylene generators capable of supplying the total requirements of the whole plant through a complete piping system of distribution. Duplex generators are often used so that the acetylene supply continues without interruption while one side of the generator is being recharged with carbide. Next to the generator house residue pits are provided, into which the generator sludge is discharged. When this residue is settled, the clear water is drawn off and the hydrated lime recovered may frequently be used to advantage. Oxygen is distributed through a separate, parallel piping system to the various stations conveniently located throughout the plant. Oxygen cylinder manifolds, also of duplex design,

are used to effect a constant dependable supply. If, for example, a 20-cylinder manifold is used, the 10 cylinders on one side are in operation while 10 empty cylinders on the other side are removed and replaced with full ones so that the supply of oxygen is never interrupted during any of these cylinder changes.

This system of gas distribution through piping is advantageous in most instances as it eliminates the handling expense and loss of time

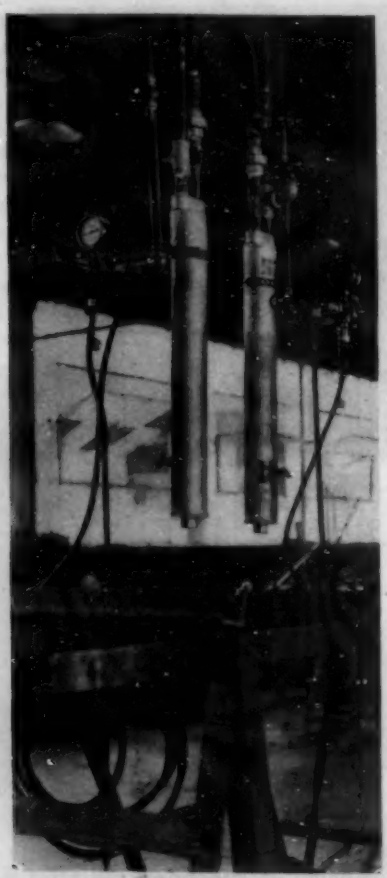


FIG. 4—WELDING STATIONS ARE LOCATED AT CONVENIENT PLACES

incurred when welders have oxygen and acetylene cylinders at their individual jobs. Generated acetylene also provides the most economical supply of this gas. The installation of the equipment and piping should be made under the direction of the engineers of the oxygen manufacturer or generator manufacturer, as they are thoroughly familiar with the regulations of the National Board of Fire Underwriters and other bodies.

At each welding station throughout the plant the acetylene branch has an hydraulic back pressure valve, if low pressure acetylene is used. If a medium pressure acetylene generator is installed, an acetylene station regulator is used instead of the hydraulic back pressure valve. At each station the proper type of welding blowpipe is provided for the particular operation which is being performed.

Facilities of this type place the oxy-acetylene process ahead of any other production methods. Great economy and efficiency as well as

FIG. 5—WELDERS TRAINED TO QUALIFY UNDER PROCEDURE CONTROL

FIG. 6—TRADE SCHOOLS TEACH WELDING TO THEIR STUDENTS

infinite saving of labor are to be effected by the use of the proper oxy-acetylene facilities. Such installations are increasing as plants adopt welding for production.

PROCEDURE CONTROL

The early hesitancy of production managers to adopt welding as standard practice was in most cases founded on what seemed to them a lack of assurance that the process was consistently dependable. They would admit that welding was a thoroughly sound and advantageous

method when properly done, but would always raise the question as to how they could be sure that the welds were all properly made. Within recent years a great deal of research has been conducted in all types of welding work and the establishment of procedure control welding has applied the principles of production engineering to the welding process. Procedure control has afforded industry complete assurance of successful results in welded construction and consequently has been a most important step in the development of the process as a production method. Uniform high quality welds in all types of work are assured by conducting

FIG. 7—LONG OVERLAND PIPE LINES ARE WELDED THROUGHOUT

welding under strict procedure control methods. The conditions which caused varying results in welds were studied, and a careful study of methods revealed that the proper control of the welding operation would guarantee uniformly satisfactory results in welding at a reasonable cost to the producer.

It is necessary to inform all those who are responsible for managing production, of the several distinct features of procedure control which will guarantee successful results. These requirements for successful welding differ very little from those necessary to obtain success with any other operation. The six requirements of procedure control have often been referred to, and they are again listed below as they form the most important basis for any discussion of this subject:

(a) Check of the welders—to see that only competent operators are used. Further, that they prove their ability by successfully passing the qualification tests, preferably tests simulating the particular operation.

(b) Selection and inspection of material—to make certain that only material suitable for welding is used and that proper welding rod is selected.

(c) Design and lay-out of welded joints—to insure that the joint is correctly designed for welding.

FIG. 8—FOR STRONG AND DUCTILE PIPE-JOINTS

FIG. 9—"GAS WAGONS" SUPPLY OXYGEN AND ACETYLENE FOR PIPE LINE WORK

(d) Preparation for welding—to see that preparation and assembly are the best for welding.

(e) Organization and welding technique—to see that the welding is carried on in the most satisfactory and economical manner and that the welding itself is correctly done.

(f) Inspection and test—to check whether the above items of the welding procedure have been followed and to see that proper welding results. The test of the completed work is an additional assurance that the welding installation will give satisfactory service.

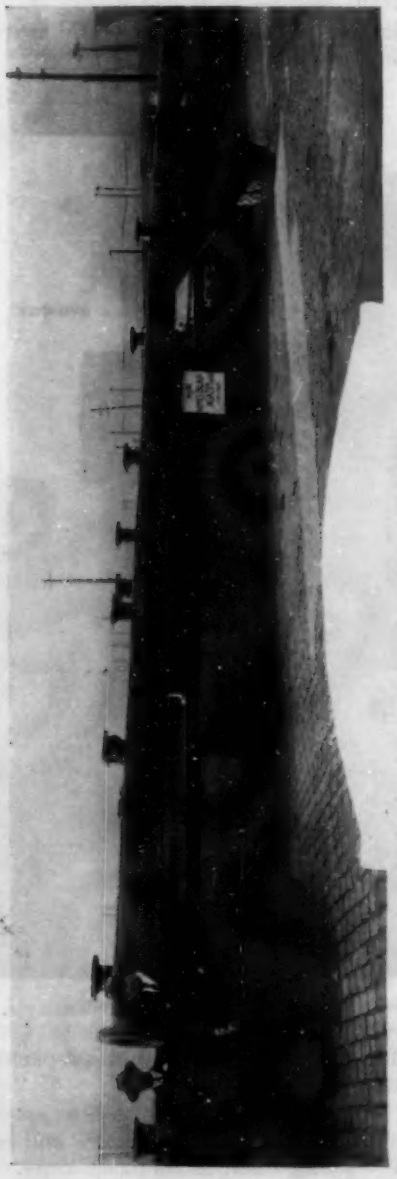


FIG. 10—POWER PLANT HEADERS ARE WELDED

Procedure control methods have been adopted today in nearly all industries using the process. With the above six factors as a guide procedure controls can be written to apply definitely to any special industry or application. Some of the fields in which procedure control methods have proved vital to success have been those of pipe lines, piping systems, welded pressure vessels, airplane assembly, and structural steel buildings.

FIG. 11 (TOP)—FOR INDUSTRIAL PIPING
FIG. 12 (LOWER)—BENDS AND REDUCERS ARE EASILY FABRICATED

In order to enable welders to pass the severe qualification test imposed by requirement (a) of procedure control, good training facilities have been established in many parts of the country. The increased use of production welding under procedure control has drawn attention to the importance of a proper training for welders. The skill of a welder is no longer difficult to determine nor is it possible to make an error in determining a man's ability. Regular courses in welding are being given in trade and vocational schools everywhere. Some large plants have established schools within their own organizations to train men for production welding. Certain labor organizations provide a means of instruction in welding and encourage members of their trade to master

the technique of this production method. Many of the leading engineering schools have welding courses for the purpose of training engineers in the general principles of welded construction and particularly the management phases.

In most of the courses for training welders, after the general principles of the oxy-acetylene process have been mastered, every effort is made to give the men a specialized training in the field in which each man intends to concentrate. In this way, competent welders are trained to do production work in some specialized line, and become experts. Outline courses for training welders for many fields of production work are furnished by the oxygen manufacturer.

The check of a welder's ability under requirement (a) of procedure control does not depend upon mere statements of previous experience.

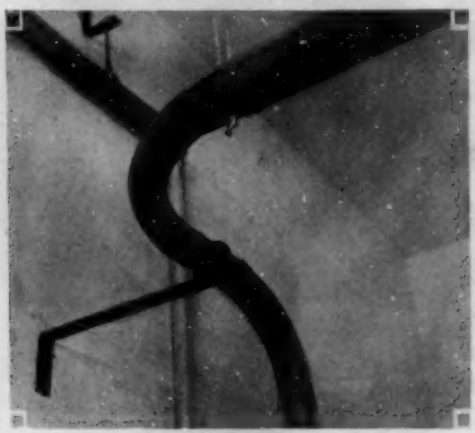


FIG. 13—WELDED BENDS ELIMINATE COSTLY FITTINGS

It involves the welding of test specimens, which are the most accurate gages of the man's skill. In addition to this qualification test, periodic tests of the welder's work are made from time to time during employment. Completed test pieces are sent to an approved laboratory for testing and the results to be acceptable must equal or exceed the minimum specified for each type of work. Various methods of making the tests are employed, depending, of course, largely upon the type of work which is being produced.

Under requirement (b) of procedure control comes the selection of the material and its rigid inspection. Just as important as the quality of the base metal is the use of the highest quality welding rod, which will insure a weld of maximum strength and the most desirable properties for the product under consideration. In the selection of the welding rod, such qualities are considered as the ductility of the weld metal, ease of manipulation of the welding puddle, freedom from a tendency to burn or to form laps or cold shuts, and the speed with which it may be deposited during the welding operation.

Requirement (c) of procedure control calls for the correct design and lay-out for the use of a welded joint. Many large pieces of machinery and other products have been completely redesigned in recent years to take advantage of welded construction. These alterations of design have resulted in more economical production and have also insured the development of a better product. In certain fields, notably those involving the use of pipe, comprehensive standards for welded design have been developed by welding engineers.

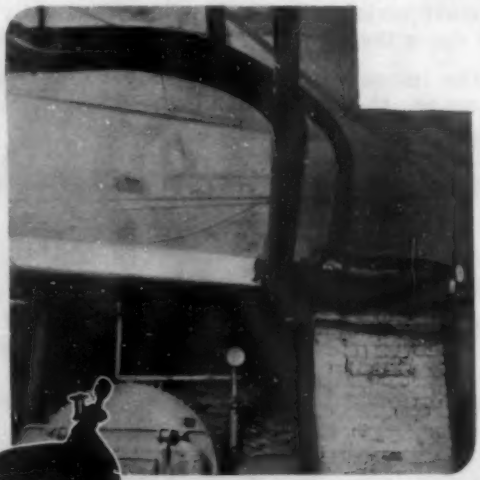


FIG. 14 (ABOVE) — WELDED DOMESTIC INSTALLATIONS ARE BECOMING MORE COMMON

FIG. 15 (LEFT)—AUTOMOBILE BODY PRODUCTION INVOLVES CONSIDERABLE WELDING

Under (d), preparation and assembly, arrangements are provided to facilitate the use of welding. Under this requirement it would not be out of place to mention the use of proper jigs during the assembly of a product by welding. Jigs are designed for use by nearly every industry using welding as a production method, because the welder's time is saved

by having the product held in the proper position for the welding. In the case of some products, a jig is vital to keep the parts being assembled in the proper alignment and to prevent any possibility of warpage or buckling. This is especially true in sheet metal assembly work. The design of jigs for production welding is a very important item in procedure control.

The supervision of the welders while the actual welding is being done comes under requirement (e) of procedure control. In production welding it is very important that proper supervision be maintained in order to make certain that each welder constantly follows the correct practice for doing the particular type of work to which he is assigned.

The inspection and test provided for in requirement (f) give added assurance that the procedure followed in the production has given successful results in the finished product. The tests given to the welds vary with the different types of welded products. The various methods employed in testing welds in production work have been outlined in previous articles.

In Various Industries

The most convincing proof of the effectiveness of the oxy-acetylene process as a production method is the number of industries which have adopted it and found it the most successful method. One of the early uses of production welding under procedure control methods was in the construction of long pipe lines for oil and gas. Today thousands of miles of these pipe lines have been laid with all joints welded by the oxy-acetylene process. Ever since the first oxy-acetylene welded line was installed, pipe line engineers have recognized the advantages of this method of installation. The steady increase of installations made by this method are the greatest proof of its effectiveness. Many long pipe lines in service today carry oil and gas pressure of 500 lb. per sq. in. or higher. The welded joints, made under procedure control, are leak proof and free from maintenance cost. There is no longer any need for pipe line walkers, who used to patrol the lines constantly in search of leaks. An oxy-acetylene welded pipe joint is the strongest type of joint which can be made, as it can develop the full strength of the pipe and even exceed it wherever this is desired. Facilities for doing this work by oxy-acetylene welding makes speedy production possible. An economical source of acetylene and oxygen supply is assured by acetylene generators and manifolded oxygen cylinders mounted on suitable trucks. Efficient pipe line organizations have been developed by many companies throughout the country.

The oxy-acetylene process has also become a standard production method in the field of domestic and industrial piping installations. The complicated piping systems of large industrial power plants are most satisfactorily installed by the oxy-acetylene process. Loss of power through piping leaks is eliminated. Bends in pipes are easily fabricated right on a job, making unnecessary the use of costly fittings. The plumbing and heating industry has recently been using the oxy-acetylene process on a larger scale for the installation of steam piping systems and

hot water piping systems in large buildings. The results obtained by them have also proved that the oxy-acetylene welded joint is the ideal type of pipe joint for domestic installations.

The automobile industry has been an outstanding example of the adoption of the oxy-acetylene process for production work. The constant improvement and changing of automobile design every year has made it

FIG. 16 — FENDER ASSEMBLIES AN EASY JOB

FIG. 17—A WELDING STATION ON EVERY COLUMN FOR PRODUCTION OF REFRIGERATORS

FIG. 18—A FINISHED PRODUCT OF ALL WELDED CONSTRUCTION

necessary to use the finest assembly methods possible. Welding is vital to the construction of custom-built and experimental models, as well as in the production of the standard cars. The oxy-acetylene process is used by the automobile industry in the fabrication of many of the parts as well as in the body assembly. Some of the parts on which welding is employed are the gear shift lever assembly, the water return line, radiator shutter, muffler, water manifold and many other cast or forged parts. The assembly of a sheet steel or aluminum auto body involves hundreds of different welding operations. Aluminum is used on more expensive custom bodies and sheet steel on the cars in the quantity production class. The assembly of bodies involves such a number of operations that in most plants it is carried progressively along a conveyor system, the many sub-assemblies first being made and then passed down from operator to operator until the final completed body is assembled. Among the many applications of the process involved in auto body production are work on the pillar joints, the door panel corners, and then the complete shroud assembly. In some plants the main body seams are welded throughout by the oxy-acetylene process, the sheet metal being held in specially designed jigs to prevent any possible misalignment during the welding operation.

Among the body sub-assemblies which are made by the oxy-acetylene process in automobile production are tubular windshield frames, running board hangers, headlight brackets, fenders for tire carriers, radiator shells, supports, tool box and battery hanger brackets, and gasoline tanks. One of the final operations in the body assembly process is the attaching of the fenders to the running board. Several short welded seams are usually involved where the fender and the fender apron are joined at the front and rear ends. There are several welded joints between the fender apron and the body of the fender and fender braces. The use of the oxy-acetylene process in production work is well exemplified in the automobile industry. It is most convincing evidence of the adaptability of the process to production work as the average person is more familiar with this product than any other.

Many articles for domestic household use are today fabricated by the oxy-acetylene process. The ordinary domestic refrigerator is one of the household utilities most frequently fabricated by oxy-acetylene welding. The apparatus required to manufacture ice on a large scale has in recent years been designed in small units so that each home may have its iceless refrigeration unit. The modern iceless refrigeration unit involves the use of welding in various parts of the production process. The sheet metal on the inside lining as well as on the interior are welded by the oxy-acetylene process, as this type of seam is best suited for the subsequent vitreous enameling.

Nearly all of the parts of the refrigerating units require tight joints and absolute freedom from the necessity for repairs. The oxy-acetylene process is used in the production of these parts on many standard types of automatic refrigerators. In an absorption refrigeration unit some of the parts which are fabricated by welding include the generator, heat exchanger, absorber, charging valve, gas heat exchanger, evaporator,

rectifier and condenser. Owing to nature of the liquids and gases used in these refrigerators permanent tightness of joints is essential so that none of the confined material can escape. Refrigerators are designed to take advantage of the possibilities offered by welded construction, and the simplicity of the joints in such a complicated number of parts is most remarkable. Economy in production and perfect operation of the finished product have been secured by refrigerator manufacturers who have adopted oxy-acetylene welding as a regular production method. In the welding of the cabinet parts for a refrigerator, specially designed jigs are used to hold the sheet metal in position for the welding, as the production is carried through with remarkable speed.

FIG. 20—DEPENDABLE JOINTS ARE MADE IN AIRCRAFT FUSELAGE

Aside from refrigerators, many other articles of household use are fabricated by welding. Pieces of metal furniture, such as beds, chairs, tables, dressers, bureaus, are fabricated of sheet metal with welded joints. Metal furniture manufacturers employ oxy-acetylene welding as the assembly method giving the greatest strength and neatest appearance to the finished product. Besides the field of furniture, many items of household equipment are fabricated by welding. A variety of kitchen utensils, such as pots, kettles and pans are often assembled by welding.

Sheet metal fabrication is one of the oldest and most important fields for the oxy-acetylene process in production work. In fact, welding has been largely responsible for the extensive use of sheet metal in so many products today. The oxy-acetylene process is very popular with sheet

metal workers largely because of its flexibility, in that it permits a wide tolerance in the shearing and forming operations. Mention of a few of the more familiar sheet metal products fabricated by welding emphasizes how dependent the sheet metal industry is on the oxy-acetylene process. Sheet steel barrels and tanks are familiar industrial products which are fabricated by welding. The growing use of welded sheet metal in aircraft and automobile production is discussed in other parts of this article. The fabrication of sheet metal furniture has also been mentioned. Some other industries which are using welded sheet metal are sash and door plants, hospital ware manufacturers, office equipment plants, textile machinery manufacturers, fabricators of steel plant equip-

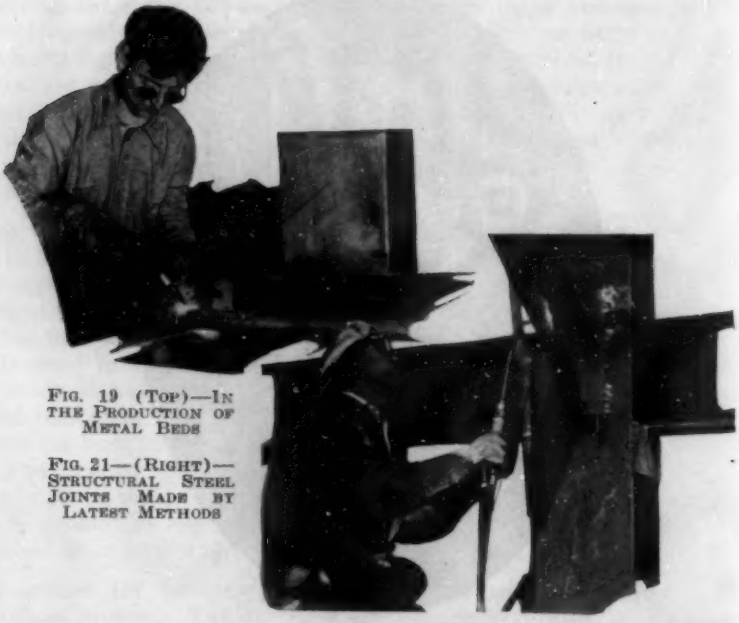


FIG. 19 (TOP)—IN THE PRODUCTION OF METAL BEDS

FIG. 21—(RIGHT)—STRUCTURAL STEEL JOINTS MADE BY LATEST METHODS

ment, ventilating system contractors, plumbing supply manufacturers, chemical equipment builders, and general plant equipment and machinery manufacturers. In addition to these, there are many manufacturers who produce sheet metal work of any type on a contract basis. Welded sheet metal work is their specialty. Sheet metal work may therefore be considered an industry by itself.

The oxy-acetylene process has taken the lead in the aircraft industry as a standard assembly method in production. The use of steel tubing in the fabrication of commercial aircraft parts such as the fuselage, landing gear and various other parts which go to make up the completed plane has necessitated the use of oxy-acetylene welding to insure the strongest possible joints. Very recently the use of welding in this industry has been extended from the fuselage to the wing construction.

Increased strength has been obtained with less weight, and the welded joint has been found to give a more uniform stress distribution than other types of joints. Procedure control methods have been more important to aircraft fabrication than almost any other field of production welding. The specialized training and severe qualification test of the welders and the careful inspection and testing of the work by the aircraft companies has established public confidence in the reliability of welded construction. The greater increase in production of aircraft in recent years has necessitated the building of many new pro-

FIG. 22—STRONG AND DUCTILE JOINTS ARE ASSURED

FIG. 23—PRESSURE VESSELS ARE DESIGNED FOR WELDED CONSTRUCTION

duction plants. Nearly all of these plants are equipped with the latest oxy-acetylene equipment for large-scale production. Acetylene generators, oxygen manifolds and gas distribution systems are standard equipment for large aircraft plants. The development of welding blowpipes specially designed for aircraft work has greatly facilitated the use of the process in this field. Nearly all American aircraft factories are standardized on oxy-acetylene welding for fuselage construction, and many of them are extending the use of the process to other parts of the

plane. The adoption of oxy-acetylene welding as a standard process in the construction of aircraft, where so much depends upon the strength and reliability of the welded joints, has been an important factor in establishing the process in other fields as a production method.

Many of the fittings for airplanes are also fabricated in aircraft production plants. The fuel tanks in particular are nearly always of welded construction. Aluminum has been found to be a suitable material for tanks, and the welded seam is the most suitable assembly method. Stainless steel exhaust manifolds, exhaust tubing, water circulation tubing for water-cooled motors, and many other accessories to the motor are fabricated, using welding as the production method.

FIG. 24—LARGE VESSELS ARE BUILT TO WITHSTAND WORKING PRESSURES OF 300 LB. PER SQUARE INCH

The use of welding in the fabrication and erection of structural steel framework for buildings has attracted public attention more than almost any other form of production welding. The general confidence in welding as a construction method is giving impetus to this new field. For some time, oxy-acetylene welding has been used on the roof trusses of a number of buildings, and recently the use of the process has been extended to other structures. Design standards have been developed for the erection of industrial buildings of considerable size, and last summer a large industrial laboratory building was fabricated and erected, entirely by oxy-acetylene welding. Another advantage of the use of welding in structural work has been the ability to construct a building without any of the serious noises which accompany the construction of a building by other methods. Entirely aside from the engineering advantages, this feature is leading public authorities to advocate the use of welding. In the business sections of cities and near schools and hospitals the quiet erection of new buildings is a necessity.

The fabrication of pressure vessels by the oxy-acetylene process has been one of the outstanding production developments of recent years. This equipment has been especially useful to the chemical industry, which has found that the service given by welded vessels under severe operating conditions has been extremely satisfactory. Procedure control methods are strictly observed in the production of pressure vessels, and

the vessels themselves are subjected to severe tests after completion. The hydrostatic pressure test is usually applied to pressure vessels and the welds are hammered while the pressure is maintained.

The above example of the use of welding in various industries are cited to show how universally welding is employed as a production method in prominent industries. Many other industries employ welding as a standard production method, and every year brings new developments in the use of the process for production. Well known products are constantly being redesigned to take advantage of welded construction, as manufacturers recognize the value of the process for production.

Design for Oxy-Acetylene Welded Piping

R. W. Boggs†

IT has been repeatedly emphasized that in order to obtain the maximum benefits of welded construction, the engineers responsible for the design of the product must be familiar with the advantages and possibilities of welding and must have at their disposal data which will enable them to apply welding most efficiently to the particular product under consideration. The rapidly increasing use of oxy-acetylene welding for the construction of pipe lines and piping systems for all type of service has brought about a demand for specific information that will enable engineers, architects and others to design and specify welded pipe lines and piping systems in accordance with the best practice.

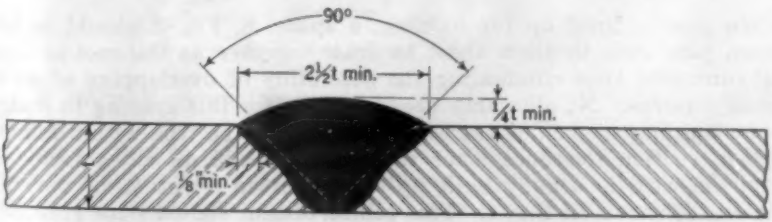


FIG. 1—OPEN SINGLE-VEE BUTT WELD

This article summarizes the design recommendations for oxy-acetylene welded line joints in steel and wrought iron pipe. These recommendations are fast becoming the standard designs for the welding of both overland and industrial piping.

Open Single Vee Butt Weld

The open single vee butt weld, Fig. 1, is the type of weld most extensively used for steel and wrought iron pipe and is the standard welded line joint; it is easy to make, of low cost, and comprehensive tests on

† Oxweld Acetylene Co.

full-sized specimens of all sizes of pipe commonly welded have shown it to be the strongest.

The open single vee butt weld is the standard line joint; *it is recommended for standard, extra heavy and double extra heavy steel or wrought iron pipe for all pressures and services.*

Pipe to be joined by this weld is supplied by the manufacturer with ends machine-beveled as shown in Fig. 2. The bevel does not extend to the inner wall of the pipe, a flat portion about 1/16 in. wide is left to facilitate lining up and weld depth penetration. This also serves to strengthen the edge during transit and handling before welding.

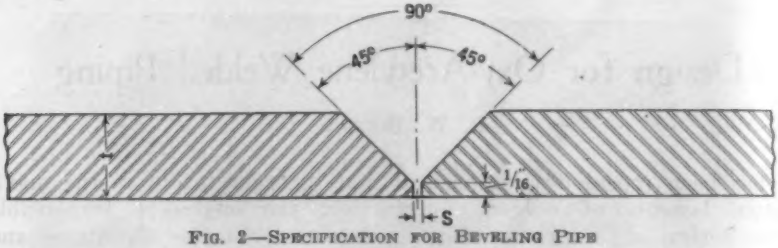


FIG. 2—SPECIFICATION FOR BEVELING PIPE

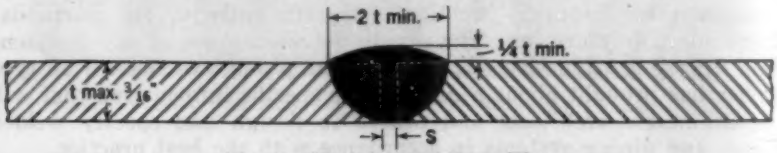


FIG. 3—OPEN SQUARE BUTT WELD

When pipe is lined up for welding, a space, S, Fig. 2 should be left between pipe ends to allow them to draw together as the cooling weld metal contracts, thus eliminating the possibility of overlapping edges or residual stresses. No allowance need be made for this spacing in design layout of piping system, as the overall length will be true within reasonable construction tolerance after welding. To add an extra factor of safety, the weld is usually built up or reinforced about ¼ of the wall thickness, as shown in Fig. 1. This reinforcement should slope gradually from the center down to the surface of the pipe along the sides of the weld. The width of the weld should ordinarily be about 2½ times the thickness of the pipe wall. In executing this type of weld, fusion to the depth indicated in Fig. 1 should be obtained, care being exercised that fusion is secured to the bottom, or root, of the joint.

Open Square Butt Weld

The open square butt weld, Fig. 3, is used for the smaller sizes of pipe, with which sufficient weld depth penetration can be obtained without beveling due to the melting of the steel with the blowpipe flame. It is in general use for pipe having a wall thickness less than 3/16 in. The reinforcement is usually made much heavier than when the open single vee butt weld is used to compensate for the lack of penetration, full

penetration being difficult to obtain without allowing the weld metal to protrude beyond the inside wall of the pipe with this type of weld.

The open square butt weld is recommended for standard pipe up to 2½ in. extra heavy up to 1½ in., and for all pipe having a wall thickness of 3/16 in. or less, for all services. For some services carrying extremely low working pressures, not subject to any appreciable expansion, contraction or bending stresses and not requiring maximum strength, this type of weld may be used for standard pipe larger than 2½ in.

Closed Single Vee Butt Weld

The closed single vee butt weld, Fig. 5, is sometimes used because of certain advantages although it is not recommended as the best practice. It facilitates lining up, especially in the case of risers where pipe lengths are simply placed one on top of the other. It insures against the forma-

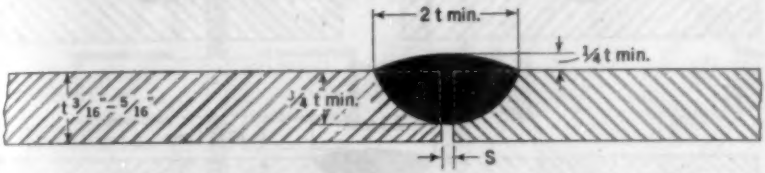


FIG. 4—OPEN SQUARE BUTT WELD FOR 3/16 TO 5/16 IN. PIPE WALL

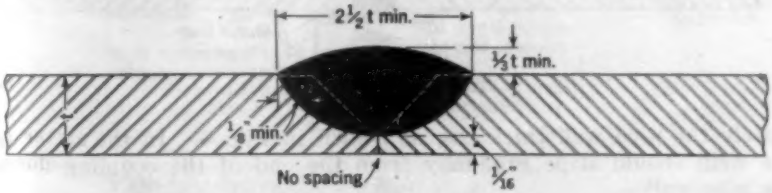


FIG. 5—CLOSED SINGLE VEE BUTT WELD

tion of protrusions on the inside of the pipe and requires less skill on the part of the welder than other types of welded joints since he is not required to fuse to the inside wall of the pipe. This type of joint lends itself readily to forward ripple welding. When the closed single vee butt weld is used, pipe ends are butted together with no space in between. The sides of the vee are thoroughly fused uniformly to the depth shown in Fig. 5. Lack of complete fusion at the bottom of the vee is partially compensated for by heavy reinforcement of the weld.

This type of weld will not develop maximum strength, but does have a strength comparable to the usual mechanical joints. It may be used for pipe in sizes up to 12 in., and for pressure and service requirements up to the equivalent of saturated steam at 250 lb. per sq. in. For sizes above 6-in., and especially for pressure services, reheating of the weld, upon completion, is recommended.

Welded Coupling

The welded coupling, Fig. 6, consists of an ordinary threaded coupling having fillet welds encircling the pipe at each end. This type of joint is

not recommended for use in welded piping construction. Although it makes a joint superior to the threaded coupling inasmuch as it is stronger and permanently tight, it is costly, requiring a coupling, the labor of threading, the labor of tightening up and two welds. The inside of the pipe is not smooth and therefore does not have maximum flow characteristics.

The joints of existing screwed lines are often made tight by welding at the couplings. The welds are used mainly as seals but also add materially to the strength of the joint. If the welds are intended merely to seal the joint they may be very light, but if additional strength is required, the fillets should be increased in size until their dimensions are approxi-

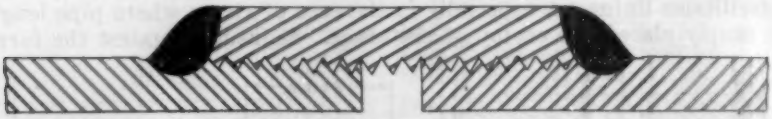


FIG. 6—WELDED COUPLING

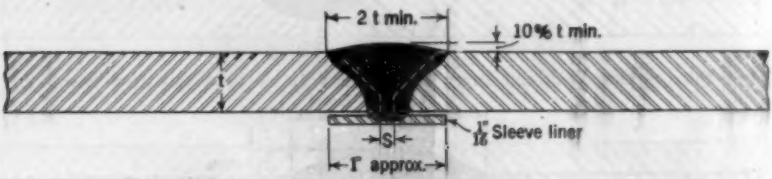


FIG. 7—BUTT WELD WITH THIN LINER

mately the pipe wall thickness, as shown in Fig. 6. In the latter case, the weld should slope gradually from the end of the coupling down to the pipe wall.

Butt Weld with Thin Liner

A type of line joint that is in the process of development, is the open single vee butt weld with thin liner Fig. 7. This type of joint has been used only experimentally up to the present and has not become standard, but indications are that it has possibilities. This joint consists of the standard open single vee butt weld backed up with a thin, sheet-steel liner which is fused in the welding operation to the bottom of the weld, as shown in Fig. 7. This joint has been designed with the idea of enabling even an operator of limited experience to produce a weld free from protrusions on the inside of the pipe, yet thoroughly fused to the bottom of the vee, and to enable an operator of average ability to produce more easily and quickly a weld of maximum strength.

Special Reinforced Joints

Two types of special reinforced welded butt joints are shown in Figs. 8 and 9. Some authorities maintain that reinforcements are never necessary with properly made welded butt joints, regardless of the service for which they are intended, and such reinforcements are not generally recommended; but they may be used for river crossings and in piping

systems for joints known to be subjected to excessive vibration and bending stresses. The bar reinforcement, Fig. 8, is ordinarily used only for the larger sizes of pipe. It consists of straps welded across the pipe weld at intervals around the circumference. The straps are either bent or ground to fit over the reinforcement of the butt weld. To be of sufficient strength against bending the straps should be as thick as pipe wall and 1/3 to ¼ the pipe diameter in width. Spacing between straps should not be more than 8 in.

The butt weld with welded split sleeve, Fig. 9, is used for practically the same purpose as the bar reinforcement shown in Fig. 8. When this

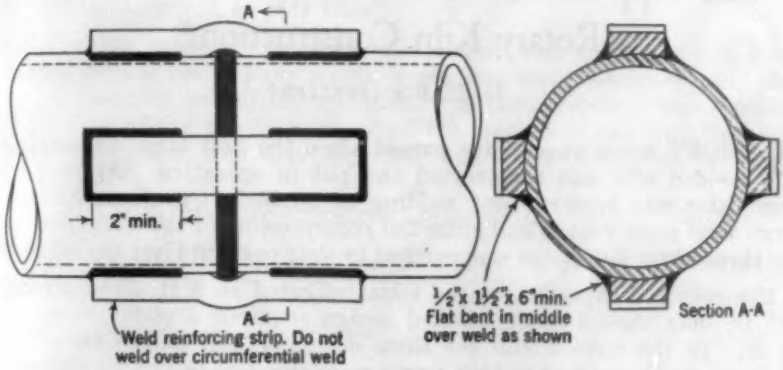

A
2" min.
A
Weld reinforcing strip. Do not weld over circumferential weld
½" x 1½" x 6" min.
Flat bent in middle over weld as shown
Section A-A

FIG. 8—WELDED BAR REINFORCEMENT

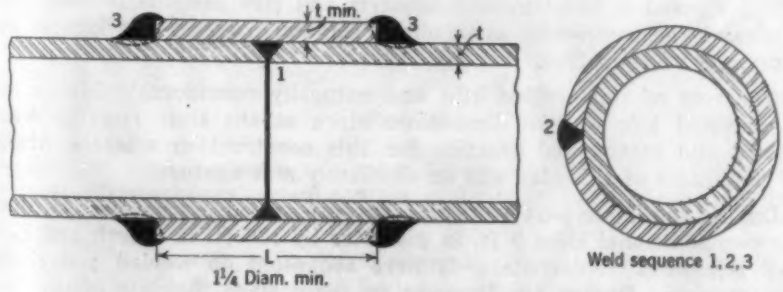


FIG. 9—WELDED SPLIT SLEEVE REINFORCEMENT

type of joint is used, a flush weld, that is, a weld with no reinforcement, is used for making the joint to be braced. A short section of pipe of larger diameter than the pipe to be reinforced is either split longitudinally on one side and slipped over the pipe for welding or split in half, placed around the pipe joint, tacked and welded longitudinally and at the ends. The reinforcing sleeve should fit closely and have a minimum length of 1¼ times the nominal diameter of the pipe to be reinforced. At least ⅛ in. space should be allowed at the bottom of the vee for the

longitudinal weld (or welds) in order that the contracting of the weld metal may draw the sleeve around the joint.

To secure maximum strength in all of the foregoing joint designs, all of the butt welds should be thoroughly fused to the joint edges and should extend completely to the bottom of the vee. All fillet welds should be thoroughly fused to the root. All welds should be of sound metal throughout.

The Application of Oxy-Acetylene Welding to Rotary Kiln Construction*

H. E. ROCKEFELLER†

ALMOST seven years have passed since the first large oxy-acetylene welded kiln was constructed and put in operation. At that time, very little was known about welding as applied to the construction of large steel plate vessels and since the requirements of the customer called for three kilns, a decision was reached to weld one and rivet the other two.

The required capacity for the kilns indicated an 8 ft. diameter and a 125 ft. long shell and the riveted design required a plate thickness of $\frac{5}{8}$ in. In the welded kiln the same design was employed as with the riveted kiln except that welded seams were specified to replace the riveted seams in the kiln shell. That the construction was satisfactory has been proved by the tests for alignment and concentricity that were made, which showed it to be more concentric and straighter than the riveted kiln, and the completely satisfactory service given by the kiln in over six years of operation.

The cost of this welded kiln was naturally considerably higher than the riveted kiln of like dimensions since at the time riveting was a known and established practice for this construction whereas welding of containers of this size was an absolutely new venture.

During the latter part of 1929, bids were issued by the same customer for two additional kilns 9 ft. in diameter by 120 ft. in length and $\frac{5}{8}$ in. wall thickness. Alternate bids were requested on welded and riveted construction. During the intervening years since the date of construction of the first welded kiln several steel plate fabricators had gained a vast experience in similar construction in the welding of hundreds of pressure vessels some of which were comparable in size with the non-pressure rotary kiln then under consideration. Welding procedures had been developed and standardized with a consequent reduction in the cost of fabrication. As was expected by those interested in the advancement of oxy-acetylene welding for this class of construction, the bids received on welded construction compared very favorably with those

*Paper presented at Annual Meeting, A. W. S., April, 1930.
†Development Dept., The Linde Air Products Company.

received for riveted construction and the contract for both kilns was consequently let for welded construction.

It is not necessary to give any detailed account of the procedures followed in the construction of these two units since the same procedure control practices were followed in general as have been established for pressure vessel construction and this latter subject has been already discussed before the American Welding Society and the details of procedure control as applied to pressure vessel construction fully covered in articles published in your journal and in *Mechanical Engineering*.

The following brief outline of the steps taken to meet the requirements of procedure control in this particular application will therefore, it is believed, be sufficient at this time:

Each of the welders was required to submit representative test specimens for tensile test. Four tensile specimens were cut from each plate submitted and on two of the specimens the reinforcement was removed. The average of the tensile tests of all the specimens covering the welds submitted by those who were approved, was 55,000 lb. per sq. in. Class

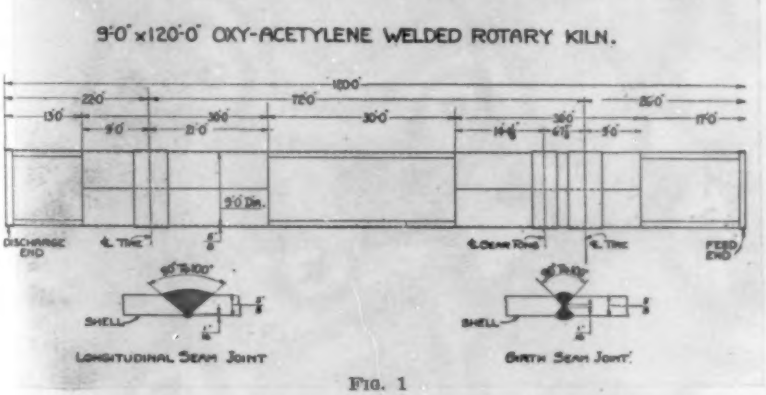


FIG. 1

A steel was used having a minimum tensile strength of 54,000 lb. per sq. in. and a maximum carbon content of 0.20 per cent. High Test welding rod was specified.

Single V welds with an included angle of 90 deg. and finish welded at the bottom of the V were called for on longitudinal seams and double V welds for the girth seams. Ordinarily in steel plate vessel construction, the longitudinal seams are subjected to the greater stress. In rotary kilns, however, the opposite is the case as the stress to which the steel is subjected results not from internal pressure, but from the load of the lining and contents, which cause the cylindrical shell to act as a beam supported at the tires.

The plates were laid out so as to provide for the minimum amount of welding and to remove the girth joints from the points of principal stress which occur at the supports. The kilns being 120 ft. in length, five courses were used, the center courses being 30 ft. in length and the

two end courses 13 ft. and 17 ft. The 13 ft. course was employed at the discharge end of the kiln because of the greater loading at this point than at the charging end. As the diameter of the kilns was 9 ft., three plates were used per course.

In the fabrication of the kiln shells, the plates were first squared, beveled for welding on a plate planer, crimped along the longitudinal edges and then rolled to the proper contour. In the two courses containing the tire and gear rings, the plates had to be punched for riveting as the usual practice of riveting these connections to the shell was retained. The welding of the 30 ft. longitudinal seams was accomplished without any difficulty, as previous experience had definitely established.

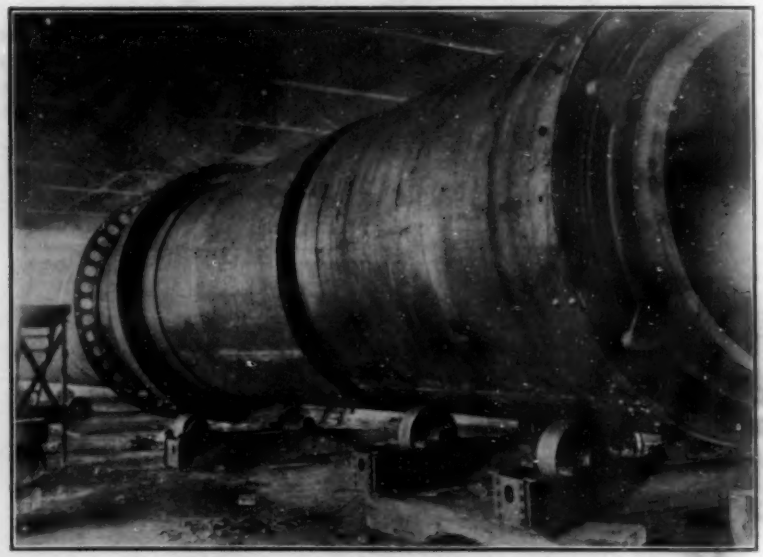


FIG. 2—END SECTION READY FOR LINING UP

that seams of any length may be entirely satisfactorily welded if the proper provision is made for the contraction of the seam during the welding. The 9 ft. diameter girth seams were welded much in the same manner as in welding ordinary pipe by proper equal spacing and tacking prior to the seam welding.

As stated previously, welding practices had been established very definitely for this class of welded plate construction at the plant where these units were fabricated and, as was expected, no delay or difficulty was encountered in the entire welded fabrication.

One unusual incident did occur during the fabrication, however, which bears mention. During the progress of the work, it was noted that in the 30 ft. section of each kiln containing the gear ring and one of the tire rings, the rivet holes had been laid out from incorrect center lines which brought both of the above mentioned attachments 5 ft. 4⅛ in.

farther from the feed end of the kiln than specified on the drawings. If riveted construction had been employed for joining the girth seams, this entire 30 ft. course on both kilns would have to have been replaced with a consequent large additional expense and considerable delay. The delay in this instance would probably have been in the neighborhood of four to five weeks inasmuch as these plates would have to have been reordered from the mill and put through the necessary forming operations prior to the joining of the sections into the kiln shells. As the

FIG. 3—CLAMPS HOLD COURSES IN ALIGNMENT FOR WELDING GIRTH SEAMS

oxy-acetylene process was being employed in the construction of these units, however, it was only necessary to remove from the 17 ft. section, the desired width, and to insert this section between two of the 38 ft. sections. The removal of the short section was accomplished by means of the oxy-acetylene cutting blowpipe, the cut edges being beveled for welding with pneumatic chipping tools. This section was then welded into the kiln shell in the same manner as the other sections and necessitated only one additional girth weld in each of the kilns.

Another feature in the construction of these units which had not been generally employed prior to this construction was the rerolling of the courses after welding the longitudinal seams. This operation was carried out in a set of 30 ft. rolls without heating the plates before rerolling with entirely satisfactory results. The rerolling of these sections both

facilitated lining up the girth seams and aided in maintaining the straightness and concentricity of the shells.

Upon completion of the construction of the two kilns, measurements were taken to determine the concentricity at the feed and discharge ends, and the straightness of the overall length. The concentricity was determined by rotating the kilns on the tire rings. The straightness of the shell was measured by the use of a transit, measurements being taken at eight points along the kiln length at the quarter points of the circumference. The measurements for concentricity indicated that the kilns would rotate with an eccentricity of between three eighths of an inch and five eighths of an inch. The transit measurements indicated that, as a cylindrical tube, the shells were within ⅝ in. of a true cylinder.

The several years of operation of the first welded kiln have proved the suitability of the oxwelded joint for this construction. The recent com-

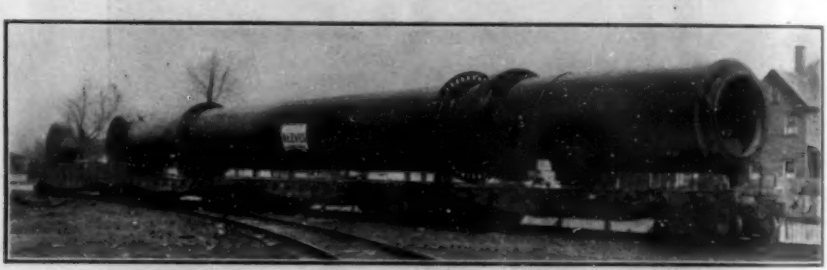


FIG. 4—WELDED LIME KILN READY FOR SHIPMENT

pletion of the two welded kilns just described is indicative of the present comparative cost of welded versus riveted construction. It would appear, therefore, that the process of construction which will be used in the future will be determined by the relative advantages of the two processes with respect to economic refinements in construction or savings incurred in operation.

As a basis for determining the present status and future possibilities of welding in this and similar applications, consideration must be given to some of the fundamental requirements of the kiln design and operation.

Since the kiln acts as a long beam overhanging its two supports, the stress in the shell at the ends will be zero, increasing gradually until it reaches a maximum at the supports. From the supports toward the center the stress decreases rapidly until the point of contraflexure is reached and then increases to a maximum at the center of the middle span. At any one position of the kiln the stresses at the top of the shell and at the bottom are opposite in value, but as the kiln rotates the stress at any point varies in magnitude from maximum tension to maximum compression for each rotation of the kiln. This continual changing load subjects the shell and joints to constantly alternating stresses and this factor must be taken into consideration, especially in the design of the girth joints.

In order to meet this condition in riveted construction, the stresses must be kept unusually low. In the two riveted kilns constructed for the customer at the time the first kiln was welded, the maximum computed stress in the kiln was only 4700 lb. per sq. in. under the worst possible condition of loading. The experience in riveted construction had shown that such a design stress was all that could be allowed for riveted construction as otherwise trouble might be expected through the constant working of the rivets resulting in their loosening and shearing off.

In order to check the design assumptions which had been established for riveted construction, a number of tests were conducted on the riveted kilns in service at one of the customer's plants after these kilns had been in service for a period of 2½ years. Measurements made across the triple riveted butt straps in the girth joints showed movements from 2 to 2 1/3 times the amount existing in the adjacent plates. This excessive movement was caused by the slipping of the sheets in and out each time the kiln was rotated. It cannot be said that this action was unexpected or unusual as it has been observed in many other cases of riveted construction where alternate loading of the joints is a function of the operation. Under the worst loading condition, therefore, the actual stresses across the riveted joints instead of being theoretically in the neighborhood of 4700 lb. per sq. in. would be in the neighborhood of 11,000 lb. per sq. in. It was, therefore, concluded that for riveted construction at least, the design assumptions were entirely logical, for if thinner plate had been used, it could be expected that the kilns would have quickly worked themselves to pieces.

In the design of the first welded kiln and the other two which have recently been completed, the same shell thickness was employed as would have been used for riveted construction. Since the welded kiln shell, however, acts as a single homogeneous cylinder, there are no concentrations of stress at the joints and consequently the actual stresses in the welded kilns at the joints should check very closely with the computed stresses. That this is actually the case was determined from tests conducted on the first welded kiln at the time similar measurements were taken on the riveted kilns which were put in operation at the same time as the welded kiln.

Some engineers have hesitated to use welding where the joints are subjected to alternating stresses. The suitability of the oxy-acetylene welded joint when subjected to such stresses has, however, been rather definitely demonstrated by the satisfactory operation of the first welded kiln for practically seven years, and should dispel any hesitancy on this score. It can reasonably be concluded, therefore, that for the same shell thickness a superior design will be obtained by the use of welded joints. It appears obvious, furthermore, where welding is used in place of riveting for the construction of kiln shells that the design assumptions may be altered to permit of a considerable reduction in the plate thickness. Even with a reduction of 25 per cent in shell plate thickness a greater factor of safety is maintained with the welded design than is secured with the usual design assumptions employed in riveted kiln construction.

Although to date advantage of this saving has not been realized in welded kiln construction, the continued extensive use and better understanding of welding will certainly warrant its consideration. The reduction in shell thickness which can safely be employed by the use of welded construction will materially reduce the weight of the kiln shell and also decrease to a very large extent the cost of fabrication.

Even though the same plate thickness as would have been used if riveted construction had been specified was employed in the last two welded kilns, a saving in weight of 21,600 lb. was effected through the elimination of the rivets and butt straps. This saving in weight represented 28 per cent of the total estimated weight of the riveted kiln and, although it represents a small percentage of the weight of the kiln when fully loaded, it means that on the welded kilns the supports and driving mechanism are required to handle 21,600 lb. less weight.

A second consideration which affects the satisfactory operation of kilns is the straightness of the kiln shell as a cylinder, and the concentricity of the feed and discharge ends. A good many people have the idea that, where riveted construction is employed, concentricity and straightness may be assured if the plates are properly laid out for riveting and that, as far as welded construction is concerned, the distortion due to welding is likely to cause considerable eccentricity in welded containers. As a matter of fact, the straightness and concentricity of the kilns which have been welded have been held within much closer limits than those which were riveted. After a number of years of operation, furthermore, it has been determined that the eccentricity of the first welded kiln is only ¾ in. whereas on the two riveted kilns an eccentricity of 1⅛ in. and 2 in. has been indicated. Since, therefore, welded containers of this nature can be built straighter and more concentric than riveted containers, this factor should also augment the use of welded construction.

A third factor which is important in kiln construction is the smoothness of the interior of the kiln shell. Where riveted construction is employed this requirement necessitates the use of outside butt strap construction so that the only protrusions on the inside of the shell are the rivet heads. The necessity of this design for riveted construction, of course, affects the efficiency of the riveted joints as described above. In welded construction an absolutely smooth interior can be maintained which gives a perfect surface for installing the lining.

As has been indicated previously, the reinforcing plates, tires and gears were designed and attached in the usual method employed in riveted construction. The expense in forming these attachments to the welded shell and their joining involved a considerable percentage of the total fabrication cost of the kilns. This construction, furthermore, has always given a certain amount of trouble in operation due to the length of the rivets which are required and the difficulty of maintaining a tight fit between the gear and tire rings and the shell. It appears obvious, therefore, as welded construction is more generally used, that the riveting of these attachments will be eliminated and that the tire and gear rings will be designed in such a manner that they can be directly butt welded into the shell and form a part of it. Special castings have been

designed for use in welded construction to meet a similar need and there appears to be no reason why a casting specially designed for welding would not very satisfactorily meet the required conditions for kiln construction.

In summing up the comparison of the economic considerations with respect to welded versus riveted construction of kilns and similar containers, there appears every reason to believe that the former construction is a logical one for such units. It is felt, therefore, that as these advantages are more fully appreciated, welding will be applied to the exclusion of riveting for such containers.

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